

Revised Edition, New Edition



A text book on

PRODUCTION ENGINEERING

Useful for IAS, IES, GATE, PSUs and other competitive exams.



Dr. Swadesh Kumar Singh

MADE EASY Publications

A Unit of MADE EASY Group



MADE EASY Publications

Corporate Office: 44-A/1, Kalu Sarai, New Delhi-110016

Website: www.madeeasypublications.org | Phone: 011-26560862, 09958995830

E-mail: info@madeeasy.in

Cover Page:

Hydraulic Press tooling of warm forming and UTM coupled with video extensometer

Production Engineering (Text book)

Copyright © 2013, by MADE EASY Publications.

All rights are reserved. No part of this publication may be reproduced, stored in or introduced into a retrieval system, or transmitted in any form or by any means (electronic, mechanical, photocopying, recording or otherwise), without the prior written permission of the above-mentioned publisher of this book.

First Edition: 2010

Second Edition: 2011

Third Edition: 2013

FOREWORD

"Invention of tools to extend the capabilities of their bare hands has been one of the greatest advances made by the ancient humans that helped in the progress of civilization. Assembling individual tools having different functions into harmonious units called machines which could perform a range of complex functions was the next major step that ushered in an industrial society which brought unprecedented prosperity to a vast majority of people. Today's comfortable lifestyles which we so take for granted owe not a little to the manufacturing sector that produces not only the goods that are indispensable to our existence but also all the machinery that makes those goods. Production Engineering is the subject that deals with the techniques of converting a variety of raw materials into useful articles.

Metalworking is one of the oldest professions practised by human beings. From the ancient village blacksmithy to the present day robotic controlled automatic manufacturing, production technology has made mind boggling advances. Today's production technologies encompass a breath taking range and can satisfactorily address humongous challenges. Be it the fabrication of flawless individual components weighing a few hundred tons each such as the bulkheads of fusion reactors or nano-scale robots that could propel themselves through the bloodstream of a human being, be it the making of very-high temperature resistant nose cone of a ballistic missile or the layer-by-layer building-up of millions of transistors and other electronic components on a single crystal of silicon to make a VLSI chip of a few mm size, today's technologies have the answers.

Ancient man may have used only a simple stone to make his tools (the flint tools of prehistoric man), but the present day engineer has a bewildering variety of materials to work with. Although still most preoccupied with the forming of metals and alloys (especially steels) using traditional methods such as casting, forging, rolling, extrusion, machining and welding, he has to master the technologies required to shape a number of other materials such as ceramics (slip casting, sol-gel processing etc), polymeric materials (blow moulding, pultrusion etc), composites (co-extrusion, sintering, polymeric curing etc) and electronic materials (photogravuring, CVD, laser processing etc). Even a mere enumeration and brief description of the large number of production technologies is a daunting task. But a full understanding of these technologies can only come about by a study of the underlying science and material behaviour under different conditions of stress, temperature and environment. This latter part requires a thorough knowledge of the structure of materials from the atomic scale to the microscopic scale and its correlation to the externally observed properties and mechanical behaviour. Further, precise mathematical analysis of the response of materials to applied stress, strain rate and temperature is a necessary concomitant to a comprehensive description of the production processes. Study of the subject of Production Engineering is thus not only useful and practical but also highly exciting and rewarding in view of its multidimensional reach and approach. "

V V Kutumbarao

Formerly Professor Department of Metallurgical Engineering, IT BHU

Formerly Director, Jawaharlal Nehru Aluminium Research, Design & Development Centre, Nagpur

PREFACE

I have great pleasure in writing the book of core subject of Mechanical Engineering viz. Production Technology/ Engineering. A thorough understanding of the concepts developed in this book will prepare the reader for more advanced course on the subject. The entire syllabus of Production Engineering is presented in a simple and lucid style to make it comprehensible to an average student.

In this book I tried to present the approach not only for competitive examinations like GATE, IES and IAS but also for university examinations of JNTU, UPTec etc. especially on the subjects like Material Science, Metrology and Production Processes. I also understood by teaching various categories of students that it becomes easy for the students when things are explained by going through the fundamentals. So in the present book I tried to explain most of the topics through the basics. The questions which already appeared in competitive examinations like GATE, IES and university exams (both subjective and objective) are incorporated in each chapter.

I would like to thank All India Council for Technical Education (AICTE), Department of Science and Technology (DST) Govt. of India, Defence Metallurgical Research Laboratory (DMRL) and my present place of work GRIET for giving me opportunity to learn and keep in touch with recent advances in the production technology either by supporting the research or providing the forum of eminent personalities to discuss various technology related issues.

I would like to express my heartfelt regard and gratitude to my teacher from whom I have learned the subject matter and which gave me inspiration to write this book. I thank Mahesh, Apurv, Devishankar Goyal, Swathi and Bandhavi for typing, drawing various figures and proofreading the text.

I would like to thank MADE EASY staff who have put their sincere efforts to develop this book timely. I would also like to thank Mr. B.Singh (Chief Managing Director, MADE EASY Group) for constructive suggestions and support.

Dr. Swadesh Singh

CONTENTS

1. Metrology

1.1	Introduction	1
1.2	Accuracy and Precision	5
1.3	Interchangeability	6
1.4	Selective Assembly	7
1.5	Limits, Fits and Tolerances	8
1.6	Allowance	10
1.7	Tolerance Sink	17
1.8	Design of Limit Gauges	18
1.9	Violation of Taylor's Principle in Gauge Design	20
1.10	Gauge Material	20
1.11	Slip Gauges	22
1.12	Angle Blocks	23
1.13	Sine Bar	23
1.14	Precision Ball Measurement	24
1.15	Vernier Calipers and Micrometer	26
1.16	Types of Errors	26
1.17	Interferometry	27
1.18	Straightness	30
1.19	Flatness	31
1.20	Comparator	31
1.21	Surface Finish	37
1.22	Screw Thread Metrology	41
1.23	Acceptance Tests	43
	Practice Questions	47

2. Material Science

2.1	Metals	53
2.2	Non-Metals	53
2.3	Organic Polymer	53
2.4	Ceramics	55
2.5	Crystal Structures of Ceramics	57
2.6	Composite Materials	59
2.7	Phase Diagrams	59
2.8	Experimental Methods of Constructing Phase Diagram	65
2.9	Fe-Fe ₃ C Phase Diagram	65
2.10	Development of Microstructure in Fe-C System	68
2.11	Family of Cast Irons	69
2.12	Effect of Alloying Element on Iron	70
2.13	Relationship between the Phase Diagrams	71
2.14	High Strength Low Alloy Steel (HSLA)	72
2.15	Defects in the Materials	76
2.16	Yield Point Phenomenon	79
2.17	Strengthening Mechanism	80
2.18	Type of Bond	83
2.19	Time Temperature Transformation (TTT) Diagram	83
2.20	Heat Treatment	86
2.21	TTT Diagrams for Hypo and Hyper-Eutectoid Steel	96
2.22	Hardenability Curves Jominy End Quench Test	97
2.23	Crystal Systems	97
2.24	Mechanism of Crystallization	100
2.25	Methods for Measurement of Grain Size	100
2.26	Crystal Directions	100
2.27	Crystal Planes	102
2.28	Creep	103
2.29	Tensile Test	104
2.30	Hardness Tests	104

2.31	Aluminum Alloys	105
2.32	Brasses	109
2.33	Bronzes	110
	Practice Questions	115

3. Casting

3.1	Design of Risers	142
3.2	Riser Design for Steel Castings	145
3.3	Gating System	147
3.4	Green Sand Mould	152
3.5	Types of Solidification	153
3.6	Die Casting	155
3.7	Centrifugal Casting	156
3.8	Slush Casting	157
3.9	Blow Moulding	158
3.10	Sodium Silicate (CO_2) Moulding	158
3.11	Shell Moulding	158
3.12	Investment Casting	159
3.13	Types of Casting Defects	160
3.14	Types of Furnaces	160
3.15	Metallurgy of Cast Steel	161
3.16	Methods of Purifying Material	162
	Practice Questions	167

4. Metal Cutting

4.1	Terminology of Single Point Cutting Tool (ASA)	180
4.2	British System	184
4.3	Normal or Orthogonal Rake System (ORS)	184
4.4	Types of Metal Cutting Process	184

4.5	Distribution of Heat in Metal Cutting	185
4.6	Types of Chips	186
4.7	Merchant's Analysis for Chip Thickness Ratio	187
4.8	Determination of Cutting Forces	189
4.9	Determination of Area of Shear Plane and Shear Strength	190
4.10	Assumptions of Merchant's Circle	191
4.11	Determination of Shear Angle	192
4.12	Velocity Triangle	192
4.13	Ernest and Merchant Theory	193
4.14	Lee and Shaffer (Slip Line Field Theory)	194
4.15	Contact Length	205
4.16	Measurement of Temperature	205
4.17	Cutting Fluids	206
4.18	Mechanism of Tool Wear	208
4.19	Effect of Parameters on Tool Life	216
4.20	Machinability	217
4.21	Economics of Machining	218
4.22	Tool Materials	224
4.23	Measurement of Cutting Forces	226
4.24	Grinding	226
4.25	Unconventional/Non-Traditional Machining Processes	231
4.26	Drilling	239
4.27	Milling	244
4.28	Powder Metallurgy	254
4.29	Jigs and Fixtures	256
4.30	Screw Thread Manufacturing	259
4.31	Gear Manufacturing	260
	Practice Questions	264

5. Metal Forming

5.1	Wire Drawing	309
5.2	Tube Drawing	310
5.3	Extrusion	311
5.4	Analysis of Wire Drawing and Extrusion	315
5.5	Extrusion Defects	324

	Content	Page xiii
5.6	Forging	324
5.7	Rolling.....	342
5.8	Punching and Blanking	352
5.9	Deep Drawing	353
5.10	Bending	360
	Points to Ponder	363
	Practice Questions	365

6. Welding

6.1	Metallurgy in Welding.....	381
6.2	Bead Geometry	383
6.3	Classification of Welding Process	384
6.4	Arc Welding	384
6.5	Resistance Welding.....	401
6.6	Solid State Welding Processes.....	412
6.7	Radiant Energy Welding.....	415
6.8	Thermit Welding Process	417
6.9	Allied Processes.....	418
6.10	Gas Welding	419
6.11	Forces in Welding.....	422
6.12	Types of Metal Transfer	422
6.13	Types of Fluxes.....	423
6.14	ISO Designation	424
6.15	Welding Positions	425
6.16	Types of Joints.....	425
6.17	Types of Weld	426
6.18	Welding Symbols.....	427
6.19	Defects in Welding	428
	Practice Questions	432
	Appendix.....	444

Index

Index.....	445
------------	-----

OOOO

Metrology

1.1 INTRODUCTION

Metrology or industrial inspection involves inspection of components produced from production, a unit to check whether the dimensions fall within the acceptable limits assigned by the consumer. Inspection is divided into active and passive type. In active inspection parts are checked when it is being produced in any production system. It is also called online inspection i.e. if something goes wrong, correction can be taken. But in passive inspection parts are checked when it is already being produced and inspection is meant for segregation of the components as good or bad. In industries generally active inspection are encouraged but it depends upon the type of application.

Parts which are produced from any manufacturing system follow a normal distribution. Machine environment can be considered as infinite universe and machined components are considered as random data collection. When data is collected randomly from an infinite universe, the data follows a normal distribution as shown in Fig. 1.1.

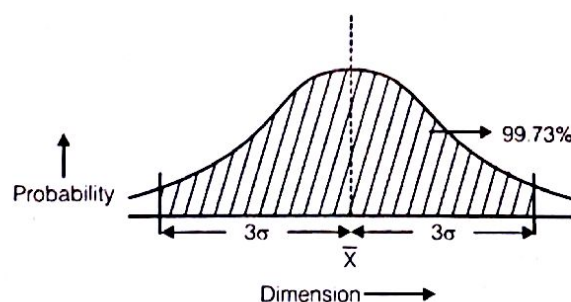


Fig. 1.1 (Normal Distribution)

Let us take one example to understand the concept. There is a lathe machine aimed at producing shafts of 25.0 mm diameter. As the shafts are coming out of the machine, no two dimensions will match and there will be some variation in the dimensions like 25.002 mm, 24.985 mm etc. It is because these dimensions are following a normal distribution. That is why it is said that what ever component you have made from your production systems, no two components will match and you

cannot duplicate the part. In the above normal distribution $\bar{X}$ is mean or targeted value of the machine and σ is the process dispersion or standard deviation. Following are the factors that may change the process or targeted mean ($\bar{X}$) value in a typical machine environment :

1. Tool and die wear.
2. Excessive machine vibrations.
3. Wear or minor failure or loosening of machine parts.
4. Change of machine and process.
5. Measurement error or change in material property.

Following factors changes the standard deviation of the process.

1. Carelessness of operator.
2. New or inexperienced operator.
3. Deterioration in the condition of machine.
4. Frequent resetting or readjustment of the process.
5. Increase variability of the material.

99.73% area of the normal distribution takes between $\pm 3\sigma$ limits of this normal distribution. It means 99.73% components will be produced in 6σ range. This 6σ is called process capability of machine. To move further with inspection let us understand normal distribution with following examples.

Example : 1.1

A lathe machine is targeted to produce shafts of 25.0 mm diameter. This conventional lathe is having process dispersion of 0.15 mm. Determine:

1. How many shafts, machine is producing below 24.9 mm?
2. How many shafts, machine is producing above 25.2 mm?
3. Normally machine will produce shafts in what range?
4. If the acceptable limits of shafts by consumer is 25 ± 0.35 mm, how many defective shafts machine is producing?

Solution :

Problems related to normal distribution can be solved by making use of normal distribution tables given at the end of book. These tables are given in terms of a variable Z which is

$$Z = \frac{X - \bar{X}}{\sigma}$$

X is the value up to which the total area under the normal distribution from $-\infty$ to X is to be calculated as shown in the given Fig. 1.2.

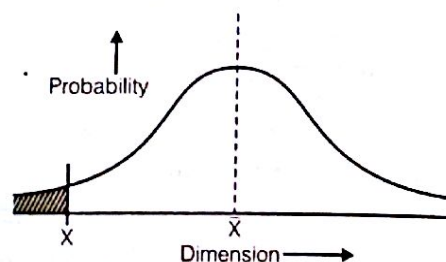


Fig. 1.2

1. In the given problem we have to calculate $= \int_{-\infty}^{24.9} P(X)dX$

where $P(X)$ is the probability function

$$X = 24.9$$

$$\bar{X} = 25$$

$$\sigma = 0.15$$

So

$$z = \frac{X - \bar{X}}{\sigma} = \frac{24.9 - 25}{0.15} = \frac{-0.1}{0.15} = -0.666$$

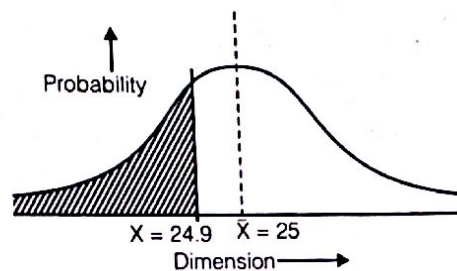


Fig. 1.3

Corresponding to this Z value, the area under normal distribution up to 24.9 mm from the table is 0.2546. So 25.46% shafts will be produced below 24.9 mm or 74.54% shafts will be produced more than 24.9 mm diameter.

2. In the above problem the shaded area has to be calculated as shown in Fig. 1.4.

$$z = \frac{X - \bar{X}}{\sigma} = \frac{25.2 - 25}{0.15} = \frac{0.2}{0.15} = 1.33$$

The area corresponding to this value from the table is 0.9082.

So the shaded area is $(1 - 0.9082) = 0.0918$. So 9.18% will be dimension more than 25.2 mm.

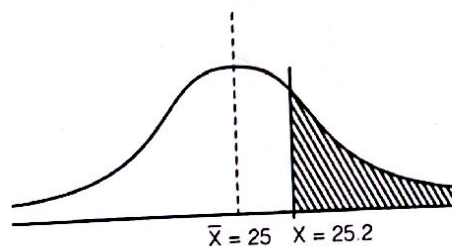


Fig. 1.4

3. Around 99.73% components will be produced within $25 \pm 3(0.15)$ mm. So machine will produce components between 24.55 – 25.45 mm range.
4. Shaded area shows the defective components produced by the machine. Since the distribution is symmetrical, upon calculating area on one side defectives can be calculated by multiplying it by 2. Area under the distribution below 24.65 mm.

$$z = \frac{24.65 - 25}{0.15} = -2.33$$

Area from the table corresponding to $Z = -2.33$ is 0.0099. So shafts below 24.65 are 0.99%.

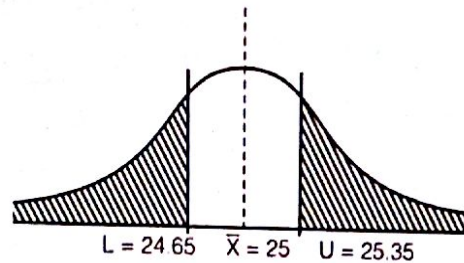


Fig. 1.5

Total defective percentage = $2 \times 0.99 = 1.98\%$

Example : 1.2

To honor guests in a function there is a machine to sprinkle fragrant water on each guest's head. In a particular random observation the machine sprinkles 4 grams of fragrant water. The normal distribution of the machine is 0.04 grams. If 2% of time machine injects 4 grams of water what is the mean amount of water machine is injecting.

Solution :

$$z = \frac{4 - \bar{X}}{0.04}$$

The value of Z corresponding to 0.02 area = -2.055 (from normal distributions tables)

$$-2.055 = \frac{4 - \bar{X}}{0.04}$$

$$\Rightarrow \bar{X} = 4.0822$$

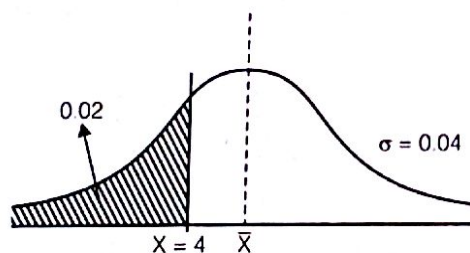


Fig. 1.6

Example : 1.3

A milling machine is programmed to produce round shape of 45 mm diameter. The machine has process dispersion of 0.2 mm. The customer has given specifications of product as 44.8 ± 0.3 . If the product is over size it can be reworked and if it is undersize it will be scrapped. In the present settings how much percentage of scrap and rework machine is produced?

Solution :**Calculation of scrap**

$$z = \frac{44.5 - 45}{0.2} = -2.5$$

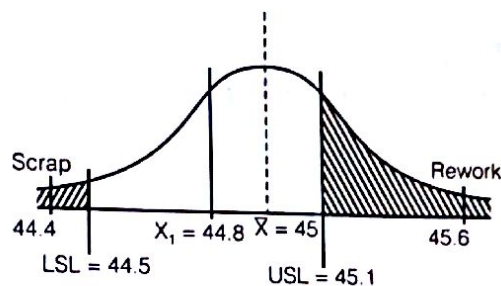
Area corresponding to this value = 0.0062

So scrap = 0.62%

Calculation of rework

$$z = \frac{45.1 - 45}{0.2} = 0.5$$

Area = 0.6915

**Fig. 1.7**So, percentage rework = $100 - 69.15 = 30.85\%$

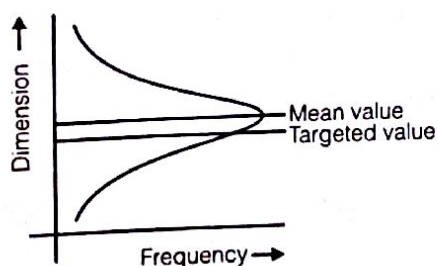
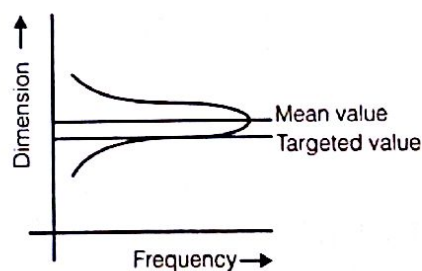
1.2 ACCURACY AND PRECISION

Accuracy is defined as closeness to the exact value and precision is repeatability. Accuracy is something related to the mean value of the parts produced and precision is related to the process dispersion. In Fig. 1.8 (i) mean value of the observations is very close to the targeted value but there are large fluctuations in the observations due to higher process capability, such systems are accurate but not precise.

In Fig. 1.8 (ii) standard deviation of observations is low and also the mean is close to the targeted value, so such systems are precise and accurate.

In Fig. 1.8 (iii) although the process dispersion of the system is low but due to the improper setting of the machine mean value is far from the targeted value. Such systems are called precise but are not accurate.

In Fig. 1.8 (iv) the process dispersion is large and the mean is far from the targeted value. Such systems are said to be neither precise nor accurate.

**(i) Accurate but not precise****(ii) Accurate and precise**

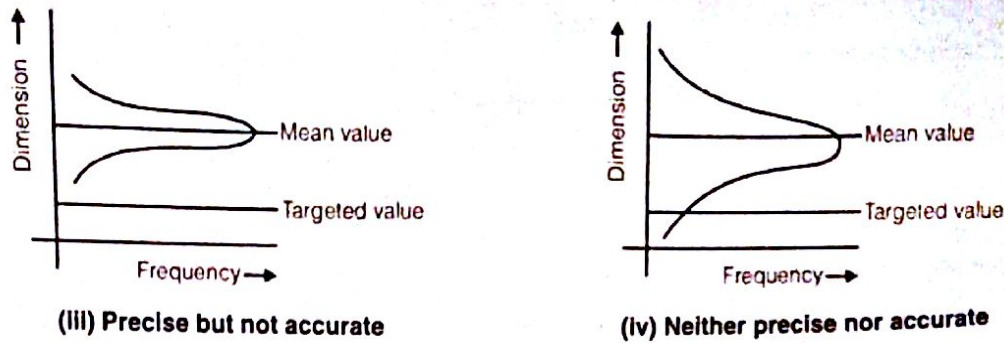


Fig. 1.8 : Accuracy Vs Precision

1.3 INTERCHANGEABILITY

Any assembly is made up of a combination of hole and shaft. Hole is any internal feature of part and may not be circular and similarly any external feature of part is called shaft, may not be circular. In most of the cases it is the hole which is made first because standard size of drills and reamers are available. If shaft is made first holes are called make to suit. As discussed earlier that it is impossible to duplicate the part, so limits are provided on the dimensions which are acceptable. This difference between upper and lower limit is called desired tolerance by the consumer. The targeted value of the hole and shaft is called basic size and nearest round number as per the standard is called nominal size.

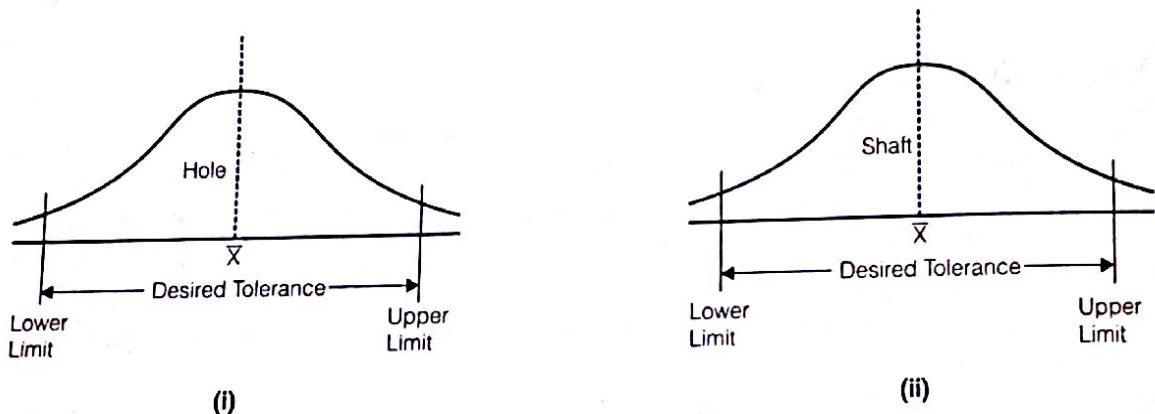


Fig. 1.9 : Full Interchangeability

Suppose there are two different machines producing holes and shafts. If it so happens that process capability is equal to the desired tolerance individually (as shown in Fig. 1.9 (i) and (ii)), if a hole is selected randomly from hole lot and a shaft is selected randomly from shaft lot, assembly can be made. Such systems are called a fully interchangeable system which does not require any inspection after machining. Interchangeability is having following advantages :

1. Cost of the assembly decreases because of holes and shafts can be made at different places where the material and the labour is cheap.
2. Standardization of hole and shaft is possible.
3. Quality of product increases.
4. Maintenance of the assembly becomes cheap and easy because when either hole or shaft fails one does not have to throw away the complete assembly and the failed parts only needs to be replaced.

1.4 SELECTIVE ASSEMBLY

To increase the quality of assembly the desired tolerances for both hole and shaft are decreasing but machines will have certain process capabilities. By converting conventional machines to NC process capability decreases but desired tolerances are decreasing more than that. Selective assembly is a mathematical procedure to achieve full interchangeability although machines are not capable i.e. process capability is much larger than the desired tolerance. Let us understand it by discussing some cases.

Case: I

Process capability of hole and shaft are equal but more than the desired tolerance.

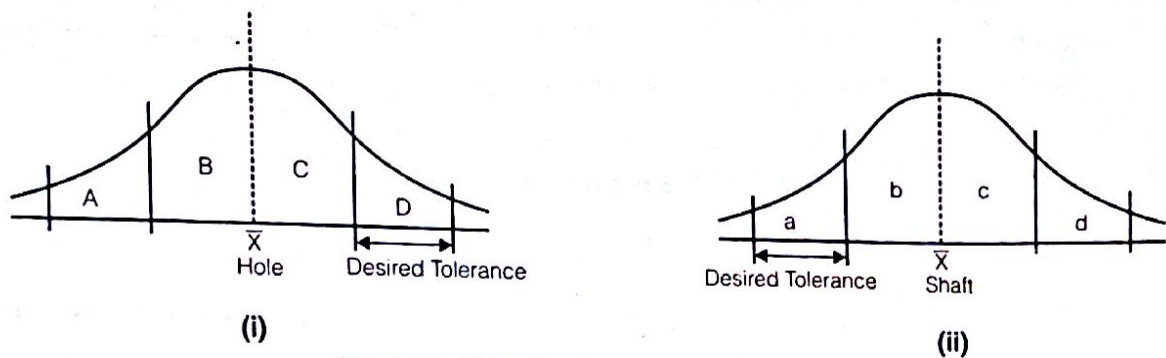


Fig. 1.10 : Selective Assembly Case - I

Let us assume that process capability is 4 times the desired tolerance of both hole and shaft. The process capability range of both hole and shaft is divided into 4 equal parts as shown in Fig. 1.10 (i) and (ii). This means in case of selective assembly each component has to be inspected after manufacturing and it is put into different subgroups according to its dimensions. The variation of dimensions within one word the subgroup is equal to the desired tolerance. So when randomly a hole is selected from subgroup 'A' and a shaft is selected randomly from subgroup 'a', assembly can be made.

Case: II

Process capability of hole is equal to the desired tolerance and process capability of shaft is worse than the desired tolerance.

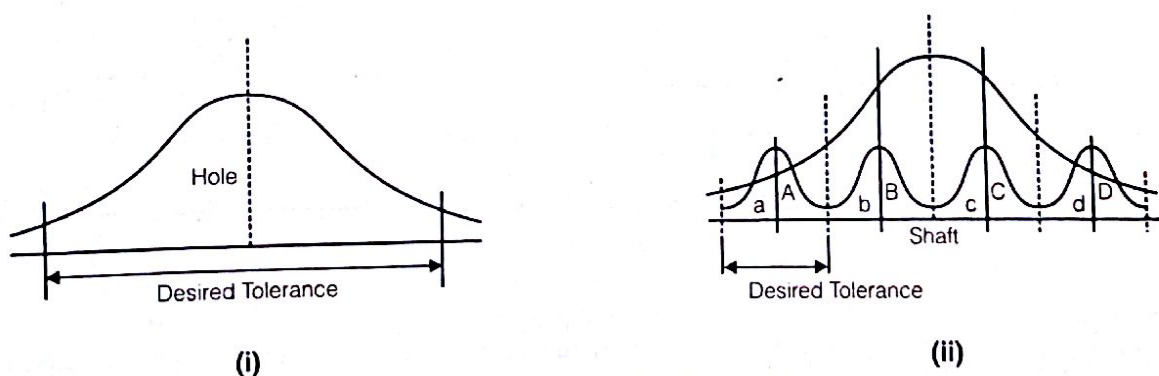


Fig. 1.11 : Selective Assembly Case - II

In this case process capability range of shaft is divided into 4 equal divisions so that variation within the subgroup is equal to the desired tolerance. For producing holes of subgroup of shafts 'a', the machine is targeted at the mean of subgroup of shafts 'a' and the holes will be directly

categorized as subgroup 'A' without any inspection because process capability of machine producing hole is equal to the desired tolerance. When variations are equal to the desired tolerances assembly can be made to give a quality of assembly.

Case: III

Process capability of both holes and shafts are different and worse than the desired tolerance.

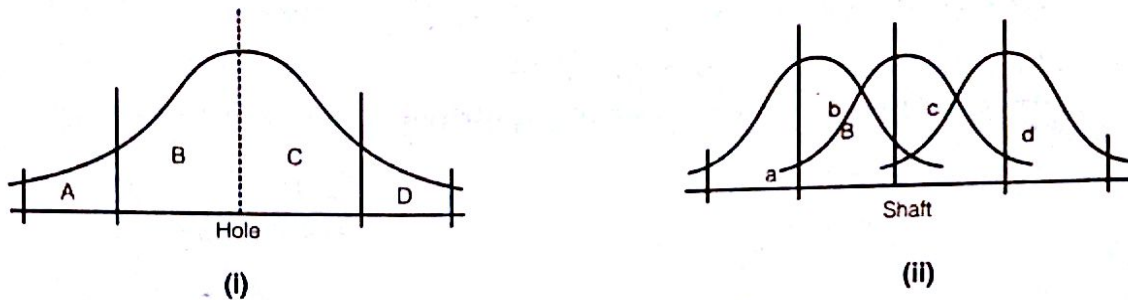


Fig. 1.13 : Selective Assembly Case - III

Let us consider that process capability of hole is 4 times the desired tolerance and process capability of shaft is not integer multiple of tolerance. Similar to the previous cases process capability of hole is divided into 4 subgroups by measuring each and every part. For shafts e.g. in subgroup 'b' shafts will be produced in two different settings. So in this case also each and every component must be inspected after manufacturing.

1.5 LIMITS, FITS AND TOLERANCES

As discussed earlier that due to process capabilities it is not possible to duplicate any part, so for assembly parts (either hole or shaft) should come within certain range of dimensions. This acceptable variation is called tolerance. Larger size is called upper limit and smaller size is called lower limit.

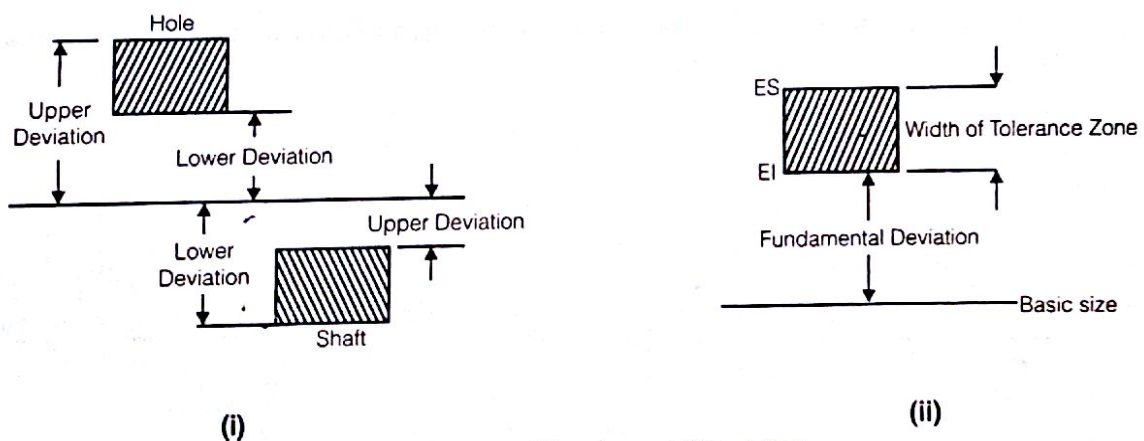


Fig. 1.13 : Tolerance and Fundamental Deviation

The distance from the basic size where the tolerance zone is situated is called fundamental deviation. The upper limit is called Ecart Supérieur (ES) (a French name) and the lower limit is called Ecart Inférieur (EI). There are 25 different types of fundamental deviation as shown in Fig. 1.14.

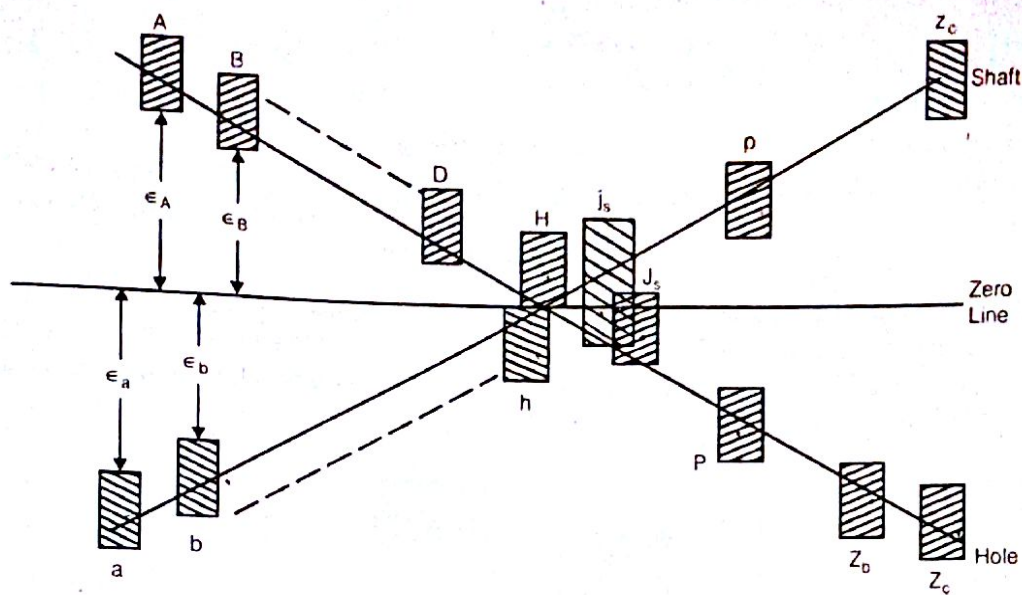


Fig. 1.14 : Variation of Different Fundamental Deviation types

Some of the alphabets are missing and some extra alphabets are there e.g. j_s , z_a , z_b and so on. Value of fundamental deviation for 'A' type hole will be same as 'a' type of shaft with a difference of sign and so on. All fundamental deviation has empirical formulas. An assembly is made up of a combination of hole and shaft. In this assembly if 'H' type of hole appears, the system is called **hole basis system** and if 'h' type of shaft is present it is called **shaft basis system**.

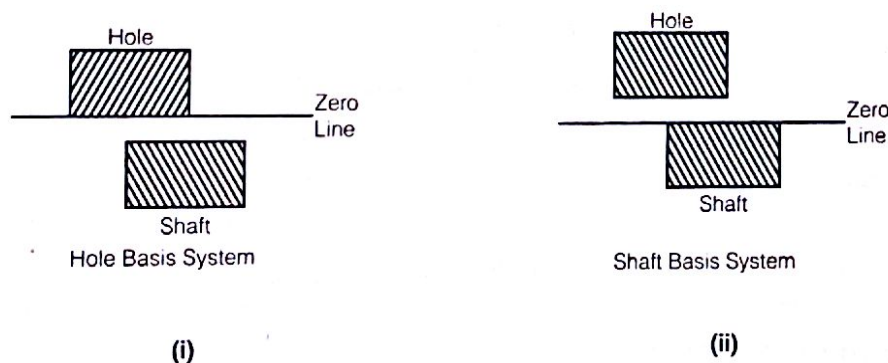


Fig. 1.15 : Hole and Shaft basis system

Fundamental deviation is also expressed as the distance between zero line and the limit closer to it i.e. either EI or e_s . Any information in capital letters refers to hole and any information given in smaller letters refers to shaft.

It is a common sense that large size shaft and small size hole will have more material. So these limits are called Maximum material limit and lower limits of shaft or upper limit of hole is called Minimum material limits. A fit is defined as the relationship between hole and shaft before assembly.

Broadly there are three types of fits:

1. **Clearance fit** : If lower limit of hole is larger than the upper limit of shaft [as shown in Fig. 1.16 (i)]. It is considered as clearance fit.

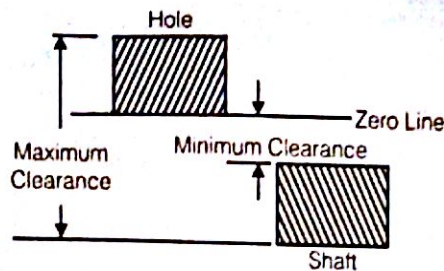


Fig. 1.16 (i) : Clearance Fit

2. **Transition fit** : This type of fit appears when there is overlap in the tolerance zones. Physically it indicates that when a part is selected randomly from hole lot and a shaft lot, some of the assemblies can be made without the application of force and for some of the assemblies force will be required.

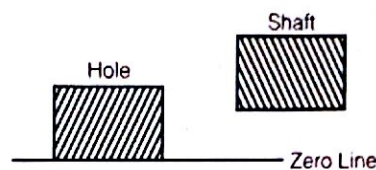


Fig. 1.16 (ii) : Transition Fit

3. **Interference fit** : If maximum size of hole is smaller than the minimum size of shaft then force has to be applied to make the assembly. Such fits are called interference fits.

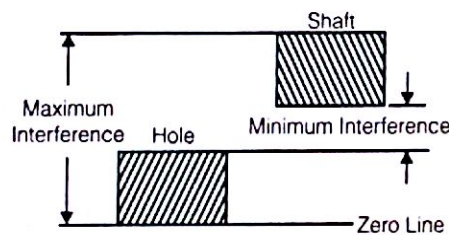


Fig : 1.16 (iii) : Interference fit

1.6 ALLOWANCE

It is defined as the difference between maximum material limit of hole and shaft. Depending upon the type of fit either it is equal to minimum clearance or maximum interference.

1.6.1 Width of Tolerance Zone

There are three systems used in the world.

1. British Standard BS-4500-1969
2. International Standard ISO: 286-1988
3. Indian Standard IS-919

But the standards of fundamental deviation and width of tolerance zone are same. As discussed previously there are 25 different types of fundamental deviations that are standardized. For the tolerance width initial recommendation was to vary tolerance according to cubical expression.

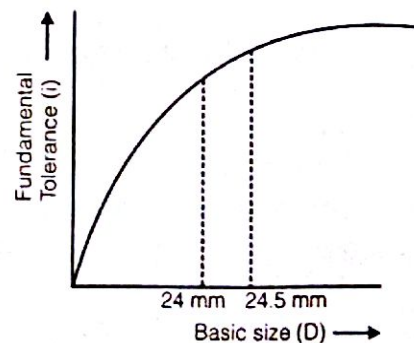


Fig : 1.17 : Fundamental Tolerance

$$i = 0.45\sqrt[3]{D} + 0.001D$$

It can be seen from the Fig. 1.17 that as the basic size increases the tolerances will also increase. For larger basic size it is not possible to control the tolerance precisely. But the major problem appeared when the basic size increases slightly e.g. from 24 to 24.5 mm, there is a change in tolerance values. So later on it was decided that there will be same tolerances between certain diameter range. These diameters are standardized as

Above (mm)	Upto and including (mm)	Above (mm)	Upto and including (mm)
—	3	80	120
3	6	120	180
6	10	180	250
10	18	250	315
18	30	315	400
30	50	400	500
50	80		

The curve of fundamental tolerance 'i' passes through the geometric mean of this diameter range as shown in Fig. 1.18. So in all the formulas of tolerance and fundamental deviation, the geometric mean diameter will be used. Initially there were 16 grades of tolerance zones. 2 more tolerance grades were added for precision industries.

These tolerances were arranged in the five step preferred series i.e. every fifth step will be multiple of 10 and the series is approximate geometric series. The calculation is shown in the Table.

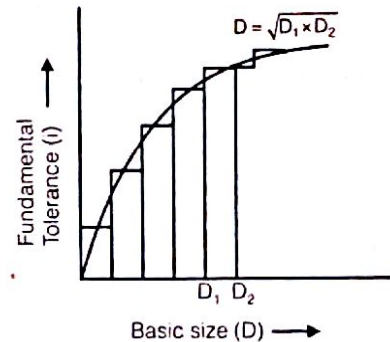


Fig : 1.18 : Modified Fundamental Tolerance

IT 01 $0.3 + 0.008 D$	IT 0 $0.5 + 0.012 D$	IT 1 $0.8 + 0.02 D$ i_a	IT 2 ar	IT 3 ar^2
IT 4 ar^3	IT 5 $(10)^{4/5} i = 6.31 i$ $ar^4 \Rightarrow 7i$	IT 6 $10 i$	IT 7 $10(10)^{1/5} i =$ $15.8 i \Rightarrow 16 i$	IT 8 $10(10)^{2/5} i =$ $25.11 i \Rightarrow 25 i$
IT 9 $10(10)^{3/5} i = 40i$	IT 10 $10(10)^{4/5} i = 64i$	IT 11 $100 i$	IT 12 $160 i$	IT 13 $250 i$
IT 14 $400 i$	IT 15 $640 i$	IT 16 $1000 i$		

This series does not follow any rule that is why it is called modified 5 step preferred series. At present

- IT 01 to IT 1 $\Rightarrow$ Empirical formula
 IT 1 to IT 5 $\Rightarrow$ Exact geometric series
 IT 5 to IT 16 $\Rightarrow$ Preferred series

Suppose a hole and shaft assembly is designated by $25 H_7 d_8$. 25 indicates the basic size 'H' is the type of hole with width of tolerance zone IT 7. 'd' is the type of shaft with IT 8 is the width of tolerance zone. This can be represented by following fit diagram.

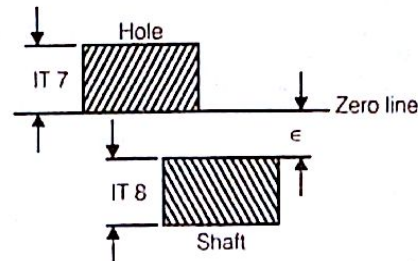


Fig : 1.19 : Fit Representation of $25H_7d_8$

When the tolerance zone is only on one side of zero line, it is called **unilateral**. When tolerance zone is on both side of zero line it is called **bilateral**.

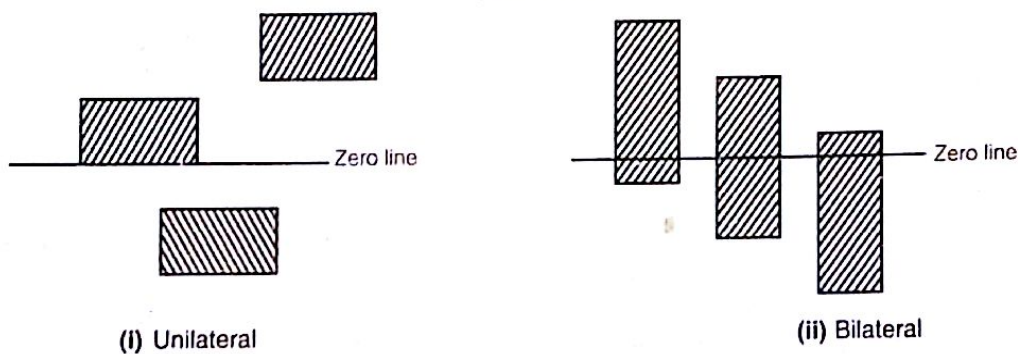


Fig. 1.20 : Unilateral and Bilateral Tolerances

Example : 1.4

A hole and shaft have a basic size of 30 mm and are to have a clearance fit with maximum clearance of 0.04 mm and a minimum clearance of 0.02 mm. The hole tolerance is to be 1.5 times the shaft clearance. Determine limits for both hole and shaft using :

1. A hole basis system
2. A shaft basis system.

Solution :

1. Hole basis system

$$X + 0.02 + 1.5 X = 0.04$$

$$X = 0.008 \text{ mm}$$

$$\Rightarrow 1.5 X = 0.012 \text{ mm}$$

$$\text{Hole} \rightarrow \text{Max} = 30.012 \text{ mm}$$

$$\text{Min} = 30.00 \text{ mm}$$

$$\text{Shaft} \rightarrow \text{Max} = 29.98 \text{ mm}$$

$$\text{Min} = 29.972 \text{ mm}$$

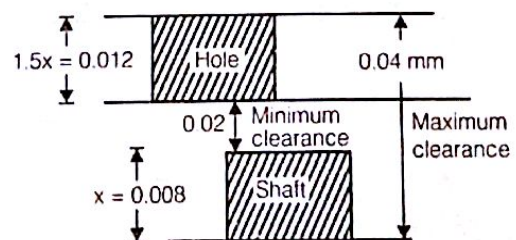


Fig 1.21 (i) : Hole basis

2. Shaft basis system

$$\begin{aligned}
 X + 0.02 + 1.5 X &= 0.04 \\
 X &= 0.008 \text{ mm} \\
 \Rightarrow 1.5 X &= 0.012 \text{ mm} \\
 \text{Hole} \rightarrow \text{Max} &= 30.032 \text{ mm} \\
 \text{Min} &= 30.02 \text{ mm} \\
 \text{Shaft} \rightarrow \text{Max} &= 30.00 \text{ mm} \\
 \text{Min} &= 29.992 \text{ mm}
 \end{aligned}$$

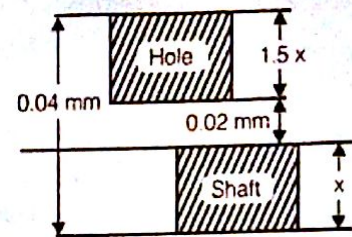


Fig : 1.21 (ii) : Shaft basis

Example : 1.5

Calculate the fundamental deviation and tolerance and hence the limits of the size for the shaft and hole for the following fit 64 mm $H_8 f_7$. The diameter steps are 50 mm and 80 mm. For shaft designation f, upper deviation is assumed as $-5.5 D^{0.41}$:

Data :	For	Tolerance
	H8	25 i
	f7	16 i

Solution :

Since 64 falls between diameter range of 50 to 80 so,

$$\begin{aligned}
 D &= \sqrt{50 \times 80} \\
 &= 63.24 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 \text{Fundamental tolerance } i &= 0.45 D^{1/3} + 0.001 D \\
 &= 1.856 \text{ microns}
 \end{aligned}$$

We should note here that although input D is in mm but i is in microns.

$$IT 7 = 16 i = 29.69 \text{ microns} = 0.0296 \text{ mm}$$

$$IT 8 = 25 i = 46.4 \text{ microns} = 0.046 \text{ mm}$$

Fundamental deviation for 'f' type of shaft

$$\epsilon_f = -5.5 D^{0.41} = -5.5(63.24)^{0.41} = -30.11 \text{ microns} = -0.03 \text{ mm}$$

$$\text{Hole} \rightarrow \text{Max} = 64.046 \text{ mm}, \text{Min} = 64.00 \text{ mm } 64_{+0.0}^{+0.046}$$

$$\text{Shaft} \rightarrow \text{Max} = 63.97 \text{ mm}, \text{Min} = 63.941 \text{ mm } 64_{-0.059}^{-0.03}$$

$$\text{Allowance} = 0.03 \text{ mm}$$

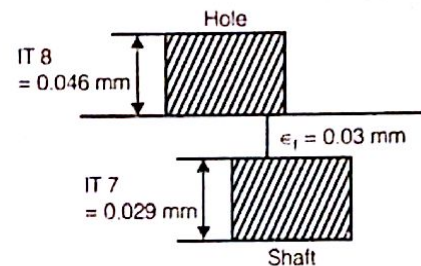


Fig 1.22 : Fit diagram of 64 $H_8 f_7$

Example : 1.6

A medium force fit $H_7 p_6$ is specified for an assembly of a hand wheel on a shaft of 50 mm nominal dia. Calculate

1. The dimensions of hole
2. The dimensions of shaft
3. Maximum interference
4. Minimum interference

Given the following:

Nominal size		Limits of tolerance for p6 shaft in microns	
Over	Upto and including	es	ei
40	50	+	+
50	65	42	26
		51	32
Nominal size		Limits of tolerance for H7 hole in microns	
Over	Upto and including	ES	EI
30	50	25	0
50	80	30	0

Solution :

The fit diagram of above problem is

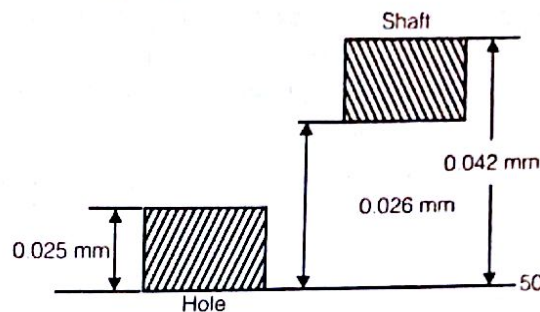


Fig. 1.23

- Hole → Max. = 50.025 mm
Min. = 50.00 mm $50_{+0}^{+0.025}$
- Shaft → Max. = 50.042 mm
Min. = 50.026 mm $50_{+0.026}^{+0.042}$
- Maximum interference = 0.042 mm
- Minimum interference = 0.026 - 0.025 = 0.001 mm

Example: 1.7

Determine and sketch the limits of tolerance and allowance for a 75 mm shaft and hole pair designated H_7S_8 . The basic size lies in the range of 50-80 mm. The multipliers for grades 7 and 8 are 16 and 25 respectively. The fundamental deviation for 's' shaft is $(IT_7 + 0.4D)$ microns.

Solution :

$$D = \sqrt{50 \times 80} = 63.24 \text{ mm}$$

Fundamental tolerance

$$\begin{aligned} i &= 0.45D^{1/3} + 0.001 D \\ &= 0.45 (63.24)^{1/3} + 0.001 (63.24) \\ &= 1.85 \text{ microns} \end{aligned}$$

$$\text{Hole} \rightarrow \text{Max.} = 75.029 \text{ mm}$$

$$\text{Min.} = 75.0 \text{ mm}$$

$$\text{Shaft} \rightarrow \text{Max.} = 75.10 \text{ mm}$$

$$\text{Min.} = 75.054 \text{ mm}$$

$$\text{Allowance} = \text{Maximum interference}$$

$$= 0.054 + 0.046 = 0.10 \text{ mm}$$

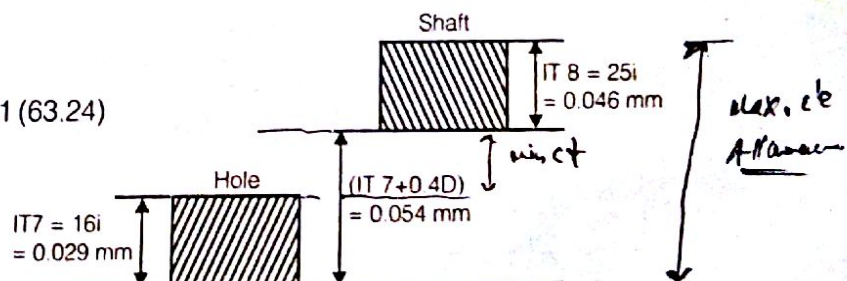


Fig. 1.24

Example : 1.8

For each of the following shaft and hole pair, calculate shaft tolerance, hole tolerance and analyze whether the pair is,

1. Clearance fit
2. Transition fit
3. Interference fit

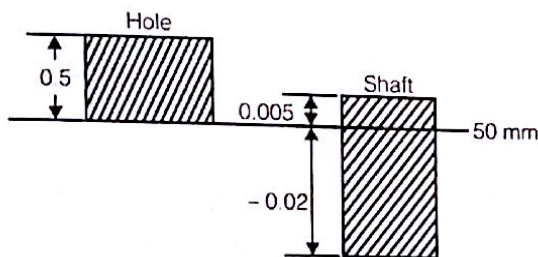
Pair 1: Hole - $50^{+0.50}_{+0.00}$ mm Shaft - $50^{-0.02}_{+0.005}$ mm

Pair 2: Hole - $50^{+0.25}_{+0.00}$ mm Shaft - $50^{+0.05}_{+0.005}$ mm

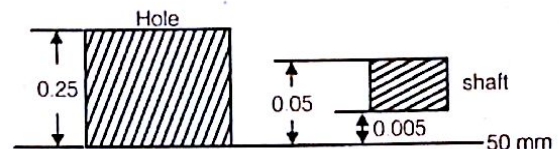
Pair 3: Hole - $50^{+0.04}_{+0.00}$ mm Shaft - $50^{+0.07}_{+0.04}$ mm

Sketch the three fits on the same zero line.

Solution :



(i) Pair 1 : Transition fit



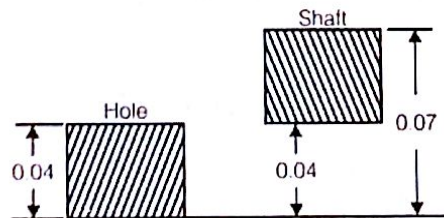
(ii) Pair 2 : Transition fit

Hole tolerance = 0.5 mm

Shaft tolerance = $0.005 + 0.02 = 0.025$ mm

Hole tolerance = 0.25 mm

Shaft tolerance = $0.05 - 0.005 = 0.045$ mm



(iii) Pair 3 : Interference fit

Fig. 1.25

Hole tolerance = 0.04 mm

Shaft tolerance = $0.07 - 0.04 = 0.03$ mm

Example : 1.9

A 35 mm diameter shaft and bearing are to be assembled with a clearance fit. The tolerance and allowance are as under

Allowance = 0.003 mm

Tolerance on hole = 0.007 mm

Tolerance on shaft = 0.002 mm

Find the limits of size for the hole and shaft if

1. Hole basis system is used
2. Shaft basis system is used

The tolerances are disposed of unilaterally.

Solution :

Allowance = Minimum clearance

1. Hole basis systemHole $\rightarrow$ Max. = 35.007 mm

Min. = 35.0 mm

Shaft $\rightarrow$ Max. = 34.997 mm

Min. = 34.995 mm

2. Shaft basis systemHole $\rightarrow$ Max. = 35.01 mm

Min. = 35.003 mm

Shaft $\rightarrow$ Max. = 35.0 mm

Min. = 34.998 mm

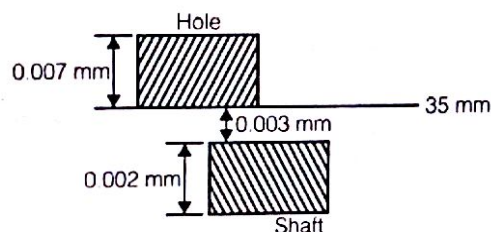


Fig 1.26 (i) : Hole basis

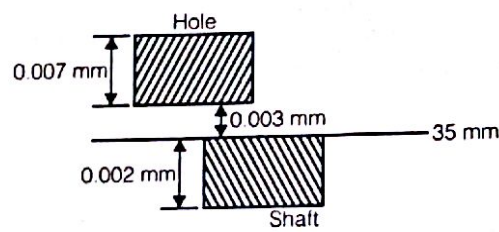


Fig. 1.26 (ii) : Shaft basis

Example : 1.10

The hole and shaft assembly of 30 mm nominal size have tolerances specified as $30^{+0.02}_{-0.00}$ mm for hole and $30^{+0.04}_{-0.07}$ mm for shaft. Determine

1. Maximum and minimum clearance (interference) attainable
2. Allowance
3. Hole and shaft tolerances
4. Fundamental deviation
5. MML for shaft and hole
6. Type of fit.

Solution :

1. Maximum clearance = 0.09 mm
Minimum clearance = 0.04 mm
2. Allowance = Minimum clearance = 0.04 mm
3. Hole tolerances = 0.02 mm
Shaft tolerances = 0.03 mm
4. Fundamental deviation of shaft = 0.04 mm
5. Maximum Material Limit for hole = 30.0 mm
Maximum Material Limit for shaft = 29.96 mm
6. Clearance fit.

1.7 TOLERANCE SINK

Suppose a component of geometry shown in Fig. 1.28, has to be made from a round bar of 50 mm diameter and 200 mm length on a conventional lathe having process capability of ± 0.15 mm. After turning to $\phi 40$ mm point A is taken as reference and a cut is made at 50 mm length. The process capabilities will come as tolerances in the given section. After turning $\phi 30$ mm section by taking same point A as reference a cut is made at 190 mm. So some tolerances will appear in the overall length. 140 mm length section of the component will be the sink. A design engineer keeps one section of the part blank (without tolerance) so that production engineer can dump all the tolerances on that section which becomes most inaccurate dimension of the part. Position of sink can be changed by changing the reference point e.g. in the same problem, for turning 140 mm section if machine takes point B as reference, overall length will become sink.

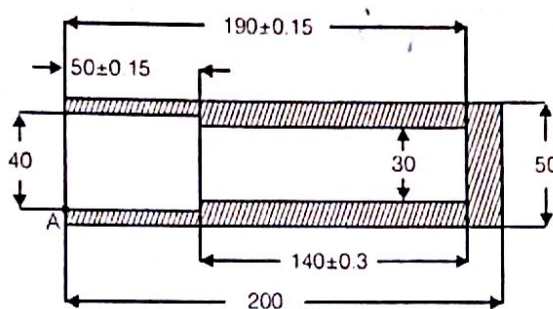


Fig. 1.28 (i)

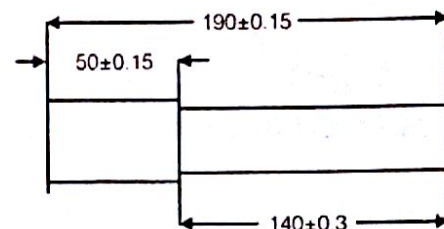


Fig. 1.28 (ii)

Tolerances for the sink is the cumulative sum of all the tolerances and only like minded tolerances can be added i.e. either equally bilateral or equally unilateral.

Example : 1.11

A part shown in Figure is machined to the sizes given below

$$P = 35 \pm 0.08$$

$$Q = 12 \pm .02$$

$$R = 13^{+0.04}_{-0.02}$$

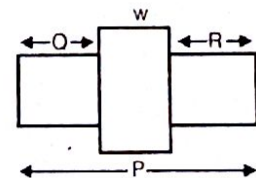


Fig. 1.29

With 100% confidence, the resultant dimension W will have the specification

Solution :

In the above problem dimensions P and Q are equally bilateral. So R also has to be converted into equally bilateral. This can be done by raising the basic size by 0.01 mm. Here section W is the tolerance sink. So

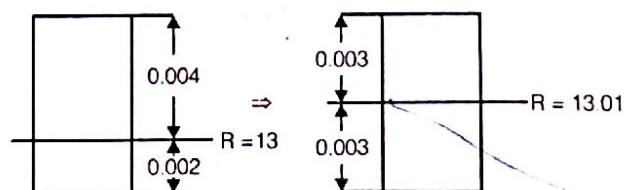


Fig. 1.30

$$\begin{aligned} \text{Basic size of } W &= P - (Q + R) \\ &= 35 - (12 + 13.01) = 9.99 \end{aligned}$$

$$\begin{aligned}
 \text{Tolerance} &= \text{cumulative sum} \\
 &= 0.08 + 0.02 + 0.03 \\
 &= 0.13
 \end{aligned}$$

So $W = 9.99 \pm 0.13$ same dimension can be written as by the same procedure by shifting basic size up by 0.01 mm.

$$W = 10^{+0.12}_{-0.14}$$

Method 2 : (Short cut)

$$W = P - (Q + R)$$

$$= 35^{+0.08}_{-0.08} - (12^{+0.02}_{-0.02} + 13^{+0.04}_{-0.02}) \text{ (add upper and lower limits separately)}$$

$$= 35^{+0.08}_{-0.08} \rightarrow 25^{+0.06}_{-0.04}$$

(-)

$$= 10^{+0.08 - (-0.04)}_{-0.08 - (-0.06)} = 10^{+0.12}_{-0.14}$$

(same result)

1.8 DESIGN OF LIMIT GAUGES ✓

Absolute measurement is a time taking process and a technical worker is required to carry out the aforesaid task. This makes the inspection expensive and hence the cost of product. Gauges (GO or NO GO) are designed to check both holes and shafts that whether they come within their tolerance limits or not. But if the job is very precise then the absolute measurement is done and not gauged even if there are so many components.

The gauges used for shafts are called ring gauges [Fig. 1.31(ii)] and gauges used for checking holes are plug gauges [Fig. 1.31(i)]. When the basic size increases beyond a certain value GO and NO GO are provided on a separate handle [Fig. 1.31].

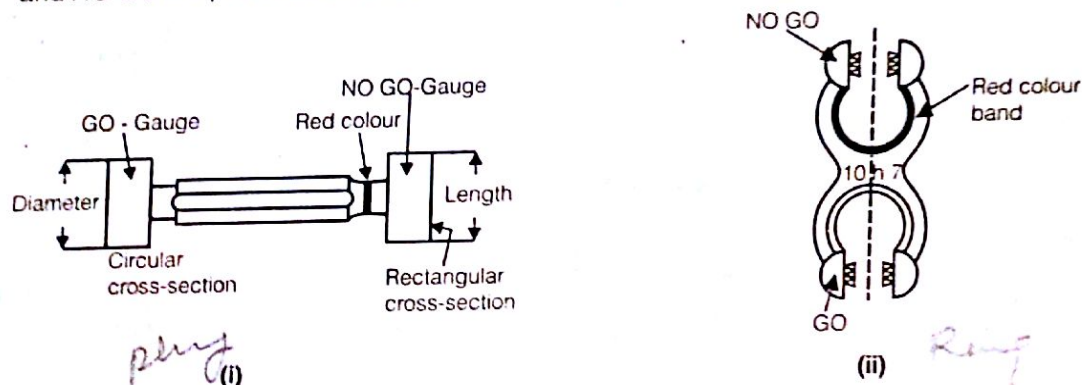


Fig. 1.31 : Plug and Ring Gauges

Since it is not possible to make anything without tolerance, so tolerances are also provided on the gauges and it is called necessary evil. Gauge tolerance is 1/10th of work tolerance. These gauges are designed according to Taylors principle in simple language which has two statements:

- ✓ 1. GO and NO GO gauges must be designed to check size as well as shape and shall be in the full form i.e. the full working length of hole or shaft.
- ✓ 2. NO GO gauges are designed to check one element at a time. e.g. suppose there is a hole which became oval during machining which one cannot see with naked eyes.

GO gauges will go completely inside the hole and cannot catch this ovality. NO GO gauge which is in the shape as shown in [Fig. 1.32(ii)] is kept in two positions as shown in Fig. 1.33. Along the major axis, NO GO gauge will go inside the hole it means there is ovality. Another element is suppose there is an unwanted cavity inside the hole. This cavity cannot be detected by the GO gauge. NO GO gauge as shown in Figure 1.33 is slightly tilted then it will go inside. At the position of cavity the axis of the NO GO gauge become horizontal.

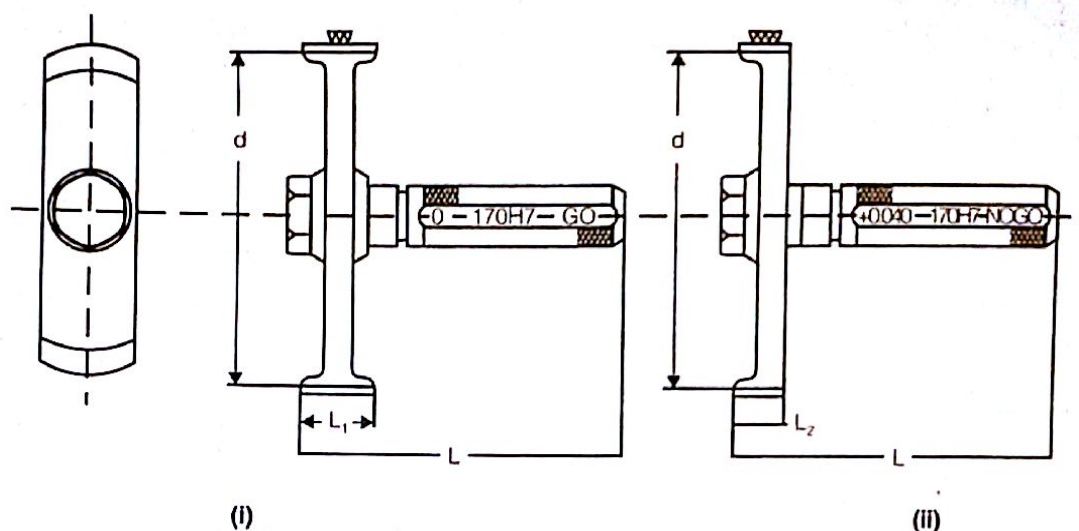


Fig. 1.32 : GO and NO GO on separate handle

Since Go gauge is moving in the complete working length to check size as well as shape of hole or shaft, there will be wear on the GO gauge. In some cases wear allowances which is $\frac{1}{10}$ th of gauge tolerance are provided on the gauge. Wear allowance is provided on the gauge only when work tolerance is greater than 0.1 mm. There are three types of gauges and the appearances of their tolerances are given in Fig. 1.34.

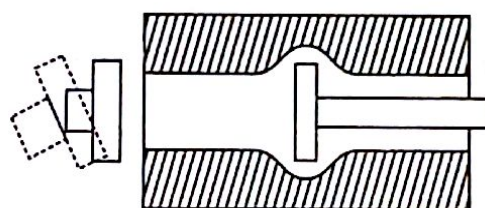


Fig : 1.33 : NO GO one element at a time

1. Work Shop Gauges : The philosophy of workshop gauge is that we will not produce anything defective and hence the tolerance on gauges will be towards the work tolerance. For hole there will be plug gauge and since it is repeatedly moving inside the hole, its diameter will keep on decreasing. So direction of wear will be in the downward direction. Ring gauge moves over the shaft so its diameter will keep on increasing so the direction of wear will be in the upward direction. A gauge can have dimension anywhere in tolerance zone. So when either hole or shaft which is within the tolerance limits near the boundaries inspected by these gauges it will be rejected. So by using these gauges some of the good parts will be treated as bad parts. If the GO gauge goes inside the hole it indicates that the dimension of hole is larger than the lower limit. If NO GO gauge does not go it means the size of hole is lower than the upper limit. If both GO and NO GO gauges goes inside the hole it means the hole is oversize and when ever GO gauges does not go it means hole is undersize. By repeatedly using GO gauge its dimension changes. GO gauge is continuously being used until wear limit which is 4μ 's is reached. Once GO gauge reaches wear limit it is thrown away and a new gauge is taken.

2. **Inspection Gauges** : The philosophy of inspection department is that already lot of effort has been taken to make the product so no good part should be rejected. So the tolerance of the gauges is away from the work tolerance as shown in Figure 1.34. It can be seen that when holes and shafts comes slightly beyond the tolerance zones, it will be accepted by the gauges. So some of the bad parts will be treated as good parts by these gauges. Since inspection gauges are already inaccurate so no wear allowance is given to the GO gauges.
3. **General Purpose (ISO) Gauge** : According to ISO: 2709 there are no separate gauge for workshop and inspection department. For general purpose gauge GO gauge is taken from workshop type and NO GO is taken from inspection gauges.

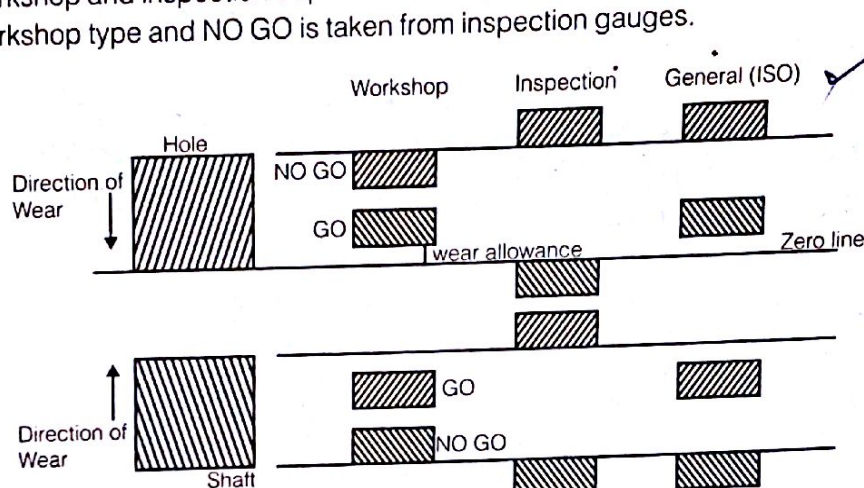


Fig. 1.34 : Tolerances of gauges

1.9 VIOLATION OF TAYLOR'S PRINCIPLE IN GAUGE DESIGN

1. As discussed earlier GO gauge has to be in full form to check shape as well as size. So it must be rigid but in actual practice GO gauges are made hollow so that it becomes light. Because it is the feel by which operator is trying to check the components.
2. GO and NO GO gauges are mounted on the same handle for simplicity which is another violation to Taylor's principle.
3. According to principle NO GO gauge must be in the form of sheet but to give life to the gauge some thickness is being provided to the gauge.

1.10 GAUGE MATERIAL

The properties of material required to make gauge out of it are :

1. **High hardness** : Since GO gauges moves repeatedly over the complete working length so the wear should be minimum.
2. **Lower coefficient of thermal expansion** : Since the difference in the GO and NO GO gauge is very small, even slight change in dimension will make the gauge incorrect.
3. **Machinability** : To finish it to exact size.
4. **Better corrosion resistance**

The commonly used materials are :

- (a) En - 24
- (b) High carbon steel

- (c) Mild steel
- (d) Inver (36% Ni) and El-inver (42% Ni)
- (e) **Glass** : This material is having specific application in ordnance factories to check the size of gun. Sometimes by accident gauge falls from the hand of operator and produces micro burr which is not visible from naked eyes. When GO gauge with this burr moves inside the barrel it produces scratches which can be very fatal. So glass is the material which is used in such cases because when gauge falls down it breaks and the operator has to use another one.

Example : 1.12

Design general type GO and NO GO gauges for components having $25 H_8/f_9$ fit. The basic size falls in the diameter range of 18-30 mm. The fundamental deviation for 'f' shaft = $(-5.5D^{0.4})$ microns. The multipliers for 8 and 9 grades are 25 and 40. Take wear allowance as 10% of gauge tolerance. Sketch the gauges with values.

Solution :

Fundamental tolerance

$$i = 0.45(D)^{1/3} + 0.001D$$

$$D = \sqrt{D_{\max} \times D_{\min}} = \sqrt{18 \times 30}$$

$$= 23.23 \text{ mm}$$

$$i = 0.45(23.23)^{1/3} + 0.001(23.23)$$

$$= 1.30 \mu\text{m}$$

$$\text{Tolerance of hole} = 25i = 32.68 \mu\text{s}$$

$$= 0.032 \text{ mm}$$

$$\text{Tolerance on plug gauges} = 0.0032 \text{ mm}$$

$$\text{Tolerance of shaft} = 40i$$

$$= 0.052 \text{ mm}$$

$$\text{Tolerance on ring gauges} = 0.0052 \text{ mm}$$

Fundamental deviation of 'f' type of shaft is

$$\epsilon_f = -5.5(23.23)^{0.4} = 19.35 \mu\text{m}$$

$$= 0.019 \text{ mm}$$

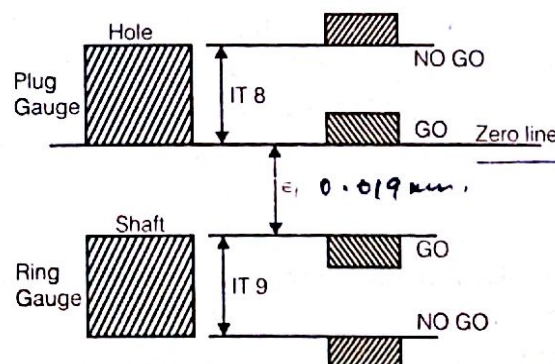
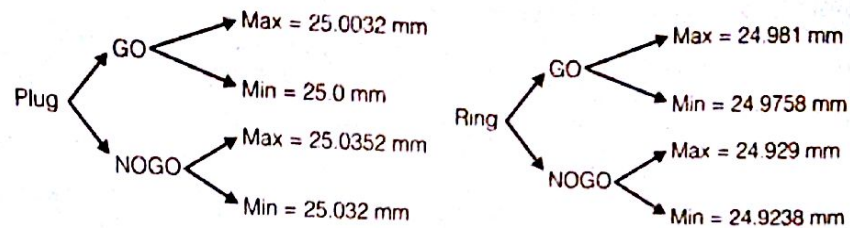


Fig. 1.35

Since work tolerance is less than 0.1 mm so no wear allowance will be given on GO gauge. So



1.11 SLIP GAUGES ✓

Slip gauges are rectangular pieces of block used to establish datum for length in industries. These gauges are available in 2 sets.

Normal set M 45

Range (mm)	Steps (mm)	No. of steps
1.001 - 1.009	0.001	9
1.01 - 1.09	0.01	9
1.1 - 1.9	0.1	9
1 - 9	1	9
10 - 90	10	9
		Total = 45

Specific set M 87

Range (mm)	Steps (mm)	No. of steps
1.001 - 1.009	0.001	9
1.01 - 1.49	0.01	49
0.5 - 9.5	0.5	19
10 - 90	10	9
1.005	-	1
		Total = 87

Let us build the dimension 25.832 mm by using normal and special sets. We begin from the last digit and move towards first digit.

Normal set :

25.832	→	choose slip gauge of 1.002 mm	...1
25.832 - 1.002 = 24.83	→	choose slip gauge of 1.03 mm	...2
24.83 - 1.03 = 23.8	→	choose slip gauge of 1.8 mm	...3
23.8 - 1.8 = 22 mm	→	choose slip gauge of 2 mm	...4
22 - 2 = 20 mm	→	choose slip gauge of 20 mm	...5

So by wringing these 5 gauges the required dimension can be build up. The faces of the slip gauges are ground and polished so that by wringing there will be fusion between the two surfaces.

Special set :

25.832	→	choose slip gauge of 1.002 mm	1
25.832 - 1.002 = 24.83	→	choose slip gauge of 1.33 mm	2

$$24.83 - 1.33 = 23.5$$

→ choose slip gauge of 3.5 mm

.....3

$$23.5 - 3.5 = 20 \text{ mm}$$

→ choose slip gauge of 20 mm

.....4

It can be noticed here that by using special set the dimension can be build by using only 4 gauges instead of 5. This makes the dimensions more accurate because every slip gauge will have some tolerance and overall build up dimension is tolerance sink.

So more is the no. of slip gauges used more inaccurate the dimension will be. That is why it is said that dimension has to be build with minimum no. of slip gauges.

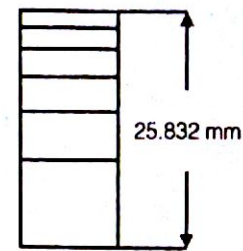


Fig : 1.36

1.12 ANGLE BLOCKS ✓

Angle blocks are hardened steel blocks similar to slip gauges but it is used for angle measurement. Top and bottom surface of the block is ground and polished. Inclined surface defines angle from the flat surface as shown in Fig. 1.37. In a typical set of angle block following angles are present.

Table

Degrees	1	3	9	27	41
Minutes	1	3	9	27	
Fractions of minutes	0.05	0.1	0.3	0.5	

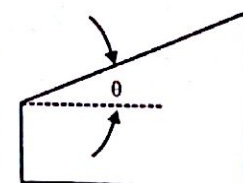


Fig : 1.37 : Angle Block

By using these 13 blocks and an optical square angle between 0° to 360° can be made, e.g. If we want to make 4° angle surface 'a' has to be wringed on surface 'b'. This will make addition of angles as shown in Fig. 1.38 (i).

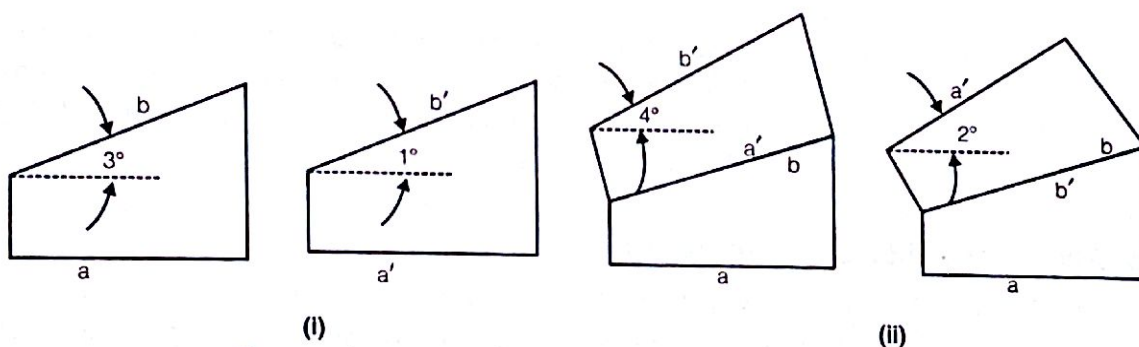


Fig. 1.38 : Addition and Subtraction of angles

If subtraction of angle has to be done (e.g. to make angle 2°) surface 'b' has to be wringed on surface 'b'' as shown in Fig. 1.38 (ii).

1.13 SINE BAR ✓

It is used for indirect measurement of an angle of a machined surface. High carbon and high Chromium material are used for sine bar as it gives good surface finish (~0.2 μ's). Two rollers of exact size are attached to the body of sine bar. These exact size rollers are made by turning a shaft in a single operation and then dividing it into two halves.

For calculating angle θ initially the dimension is being build by using slip gauges (as shown in Fig. 1.39 (ii)). These measurements are conducted by keeping the assembly on a surface plate.

In the given Figure θ can be calculated as $\sin \theta = \frac{h}{L}$

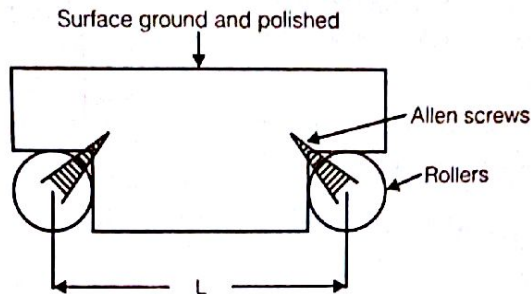


Fig. 1.39 (i) : Sine bar

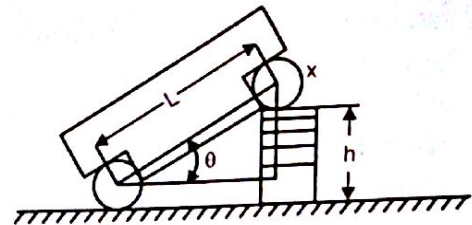


Fig. 1.39 (ii) : Assembly of Sine bar

Differentiating the above equation

$$\cos \theta d\theta = \frac{dh - h dL}{L^2}$$

$$\cos \theta d\theta = \frac{dh}{L} - \frac{h dL}{L^2}$$

Where $d\theta$ is the error in angle measurement, dh is tolerance sink in slip gauge dimensional build up and dL is error in center and center distance of slip gauge. Since slip gauges are highly accurate dh can be neglected as compared to dL , so

$$\cos \theta d\theta = -\frac{h dL}{L^2} = -\sin \theta \frac{dL}{L}$$

or

$$d\theta = -\tan \theta \frac{dL}{L}$$

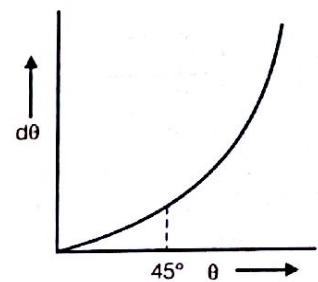


Fig : 1.40

It can be seen in the above expression that error in angle measurement is directly proportional to $\tan \theta$. The value of $\tan \theta$ increases suddenly and approaches infinity when the angle increases above 45° . So sine bars are not used to measure angle beyond 45° . Also holes are made in the body of sine bar to make the entire assembly light.

1.14 PRECISION BALL MEASUREMENT

Standard size of balls and rollers are available for measurement. With the help of these balls along with vernier, taper of any machined component can be measured. This procedure can be understood by the below examples.

Example : 1.13

Determine the taper of the V groove on a machined component as shown in Fig. 1.41.

Solution :

- Initially keep a roller of radius r_1 in the groove and by using height gauge measure h_1 as the block is kept on the surface plate. So the reference for all the measurement will be same.

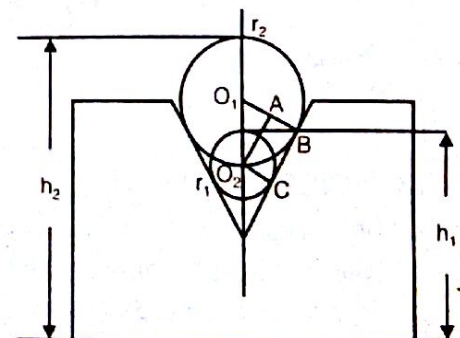


Fig : 1.41

2. After removing the first roller, a large size rollers of radius r_2 is kept and height from the top surface h_2 (as shown in Fig. 1.41) is measured.

The angle θ is calculated by mathematical calculations as shown :

In $\Delta O_1 O_2 A$

$$O_1 A = r_2 - r_1$$

$$O_1 O_2 = (h_2 - r_2) - (h_1 - r_1) = (h_2 - h_1) - (r_2 - r_1)$$

$$\sin \theta = \frac{O_1 A}{O_1 O_2}$$

$$\operatorname{cosec} \theta = \frac{(h_2 - h_1) - (r_2 - r_1)}{r_2 - r_1}$$

$\Rightarrow$

$$\operatorname{cosec} \theta = \left(\frac{h_2 - h_1}{r_2 - r_1} - 1 \right)$$

Example : 1.14

Identify the taper of the plug gauge as shown in Figure 1.42.

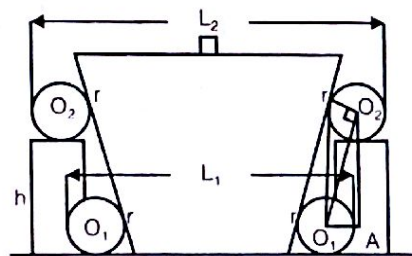


Fig. 1.42

Solution :

$$O_2 A = h$$

$$O_1 A = (L_2 - 2r) - (L_1 - 2r) = L_2 - L_1$$

$$\tan \theta = \frac{O_2 A}{O_1 A}$$

$$\tan \theta = \frac{L_1 - L_2}{h}$$

It is understood that there can be many ways to calculate these taper by using precision ball and rollers but all the methods should be practically feasible and mathematically correct.

Example : 1.15

Determine the taper of internal cavity of a machine part as shown in Fig. 1.43.

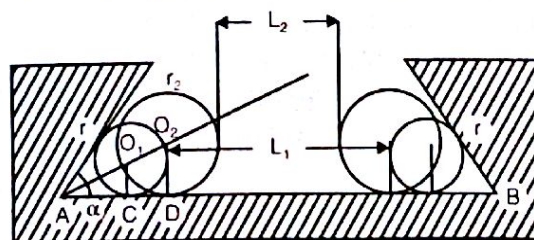


Fig. 1.43

Solution :

By putting 2 different size balls the length L_2 is calculated and in both the cases distance AB is equalized i.e. ΔAO_1C

$$\begin{aligned}\frac{r_1}{AC} &= \tan\left(\frac{\alpha}{2}\right) \\ AB &= L_1 + 2r_1 + 2AC \\ &= L_1 + 2r_1 + 2r_1 \cot\left(\frac{\alpha}{2}\right) \quad \dots(1)\end{aligned}$$

$$\begin{aligned}\Delta AO_2D \quad \frac{r_2}{AD} &= \tan\left(\frac{\alpha}{2}\right) \\ AB &= L_2 + 2r_2 + 2r_2 \cot\left(\frac{\alpha}{2}\right) \quad \dots(2)\end{aligned}$$

Equating equation (1) and (2)

$$L_1 + 2r_1 + 2r_1 \cot\left(\frac{\alpha}{2}\right) = L_2 + 2r_2 + 2r_2 \cot\left(\frac{\alpha}{2}\right)$$

$$(L_1 - L_2) + 2(r_1 - r_2) = 2(r_2 - r_1) \cot\left(\frac{\alpha}{2}\right)$$

$$\cot\left(\frac{\alpha}{2}\right) = \frac{(L_1 - L_2) - 2(r_2 - r_1)}{2(r_2 - r_1)}$$

$$\alpha = 2 \cot^{-1}\left(\frac{L_2 - L_1}{2(r_2 - r_1)} - 1\right)$$

1.15 VERNIER CALIPERS AND MICROMETER ✓

If a vernier calipers and micrometer is having same least count even then micrometer will be accurate one. It is because in vernier calipers, vernier scale is moving over a main scale and there is an area contact. So the reference plane of measurement keeps on shifting. If the contact points are more than 3, immediately it introduces redundancy because of change in reference plane. But in micrometer since there are balls which produces a point contact, the reference plane does not change. So micrometers are accurate.

1.16 TYPES OF ERRORS

There are three types of errors in measuring instruments.

- 1. System error (systematic error) :** These errors in the instrument follow a particular pattern. These errors can be neutralized by calibrating the system.
- 2. Short period error :** These errors may appear due to change in environmental conditions like humidity, temperature variations in electric instruments, fluctuations recorded while conducting tensile test on UTM. These errors can be taken care of by neglecting the irrelevant data.
- 3. Erratic error :** These errors appear due to incompleteness of any link. Such error does not follow any pattern. Their magnitude is also uncertain. So these errors have to be eliminated by inspecting the instrument before starting the experiment.

There are 2 types of mathematical errors that appear during measurements :

1. Sine Error :

$$\frac{X}{d/2} = \tan \delta\theta$$

$$\approx \delta\theta$$

$$X = \frac{d}{2} \times \delta\theta$$

$$\text{Error} = M - D$$

$$= 2X$$

$$= 2 \times (d/2) \times \delta\theta$$

$$\text{Error} = d \times \delta\theta$$

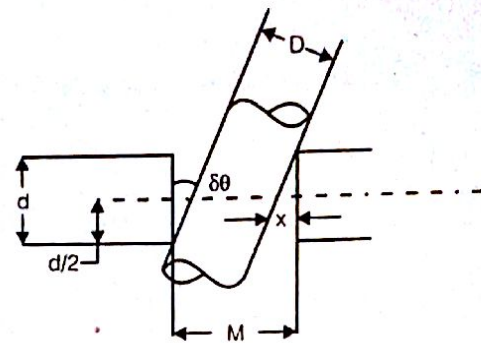


Fig. 1.44 (i) : Sine Error

Sine errors in the measurement are considerable.

2. Cosine Error :

$$M = L \cos \delta\theta$$

$$\text{Error in length} = L - M$$

$$= L - L \cos \delta\theta$$

$$\text{Since } \delta\theta \rightarrow 0 \cos \delta\theta \rightarrow 1$$

$$\text{Error} \approx 0$$

So cosine error has no significance in measurement.

It should also be noted down that to minimize errors in measurement; spherical ends should be used to measure flat surfaces and vice versa. It is because we are sure that measurement is done only between 2 points.

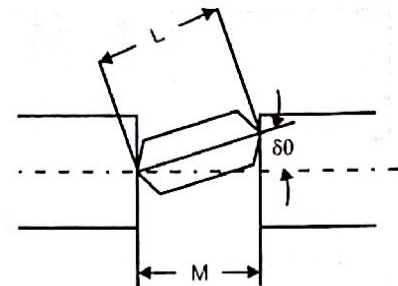


Fig. 1.44 (ii) : Cosine Error

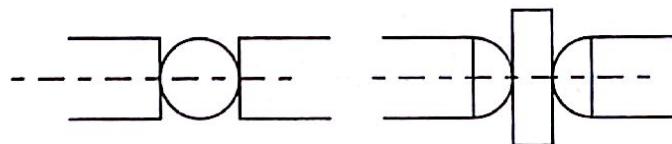


Fig. 1.45 : Measurement of Spherical and flat work pieces by micrometer

1.17 INTERFEROMETRY

A source of monochromatic light is kept at A. two rays are coming out through holes B and C and their interference is observed on the screen. At point O, the distance moved by both the rays is same so both the rays will be in phase [Fig. 1.47 (i)], which results in constructive interference this produces white band at O. At a point M or N over the screen the distance covered by both the rays is path difference of $\lambda/2$. So both rays will be in opposite phase [Fig. 1.47 (ii)]. This results in destructive interference which produces dark band. So alternatively with every $\lambda/2$ path difference there will be dark and white fringes over the screen. This concept can be utilized in the measurement by using optical flat. Optical flat is a disc made of quartz with thickness of 8-10 mm and diameter between 25-300 mm. The top and bottom surfaces of the flat are parallel.

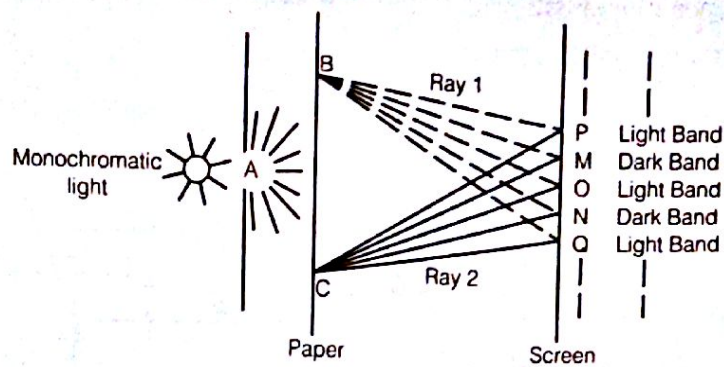


Fig. 1.45 : Interference

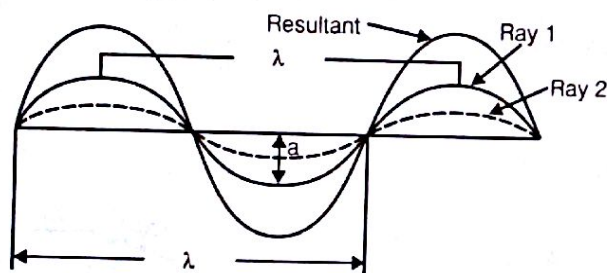


Fig. 1.47 (i) : Constructive Interference

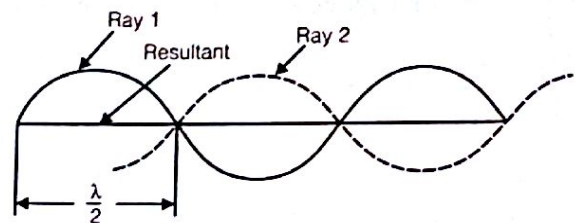


Fig. 1.47 (ii) : Destructive Interference

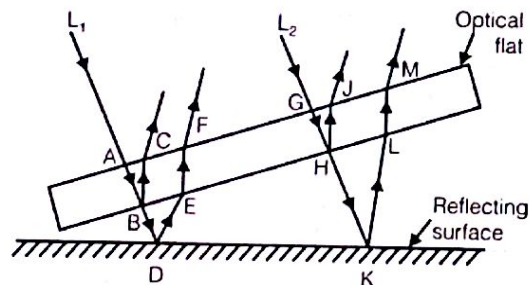


Fig. 1.48 : Optical flat over a surface

As shown in Fig. 1.48 an optical flat is kept over a tapered surface under examination which cannot be seen by naked eyes. L_1 is a ray of monochromatic light, a portion of this ray will be reflected from B and a portion will be transmitted. This transmitted ray will reflect back from the surface and come out of optical flat from F (as shown). Ray BC and EF, there will be path difference equal to $(BD + DE)$. If this path difference is equal to $\lambda/2$ there will be a dark band and if this path difference is λ , a white fringe will appear. It should be noted here that when a rays reflects back from the surface, a path difference of $\lambda/2$ is automatically created. So on the other end of optical flat the total path difference is $(HK + KL)$. Suppose there are n fringes seen in optical flat (we count no. of white fringes), then this path difference is equal to $n\lambda$.

$$HK \approx KL$$

$$\lambda = \text{wave length of monochromatic light}$$

So

$$2HK = n\lambda$$

⇒

$$HK = \frac{(n\lambda)}{2}$$

Since the angle is very small so HK can be approximated to a vertical line. Suppose L is the length of surface $\frac{HK}{L} = \tan \theta \approx \theta$.

By this equation inclination angle of the surface can be calculated.

1.17.1 Optical flat as comparator

Using optical flat difference in the size of slip gauge can be calculated from a master reference. Suppose the difference Δh has to be calculated :

From the similar triangles

$$\frac{h}{L} = \frac{\Delta h}{G}$$

⇒

$$\Delta h = \left(\frac{h\lambda}{2}\right)\left(\frac{G}{L}\right)$$

(if n fringes appear in slip gauge)

From the earlier discussion (Fig. 1.48) it can be understood that by increasing the angle between optical flat and surface, the wave lengths will quickly multiply by $\lambda/2$, so number of fringes over the surface will increase and their thickness will go down and opposite will be the case when the angle decreases.

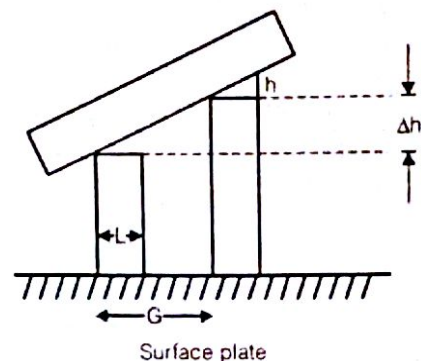


Fig. 1.49 : Flat as comparator of slip gauges

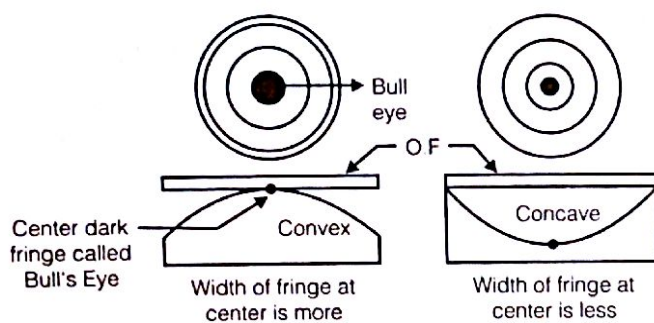


Fig. 1.50 : Optical flat over convex and concave surface



Fig. 1.51 : Wear on slip gauge

When the optical flat is kept over a convex surface, from the centre towards outward direction the angle between optical flat and surface will increase. So central fringes will be broad and in the outward direction the fringes will become thinner and thinner. Opposite will be the case when the optical flat is kept over a concave surface. Optical flats are having wide applications e.g. when it is kept over a slip gauge which has broken edge, the fringes will converge towards the edge as shown in Fig. 1.51.

1.17.2 NPL Flatness Interferometer

This instrument is used to check the flatness of any surface by comparing it with an optically flat surface i.e. base plate of interferometer. The instrument consists of a mercury vapour lamp whose radiations are passed through the green filter which gives less fatigue green monochromatic light. Light passes through a pinhole giving an intense point source. The beam is directed to the gauge to be tested via optical flat. Fringe pattern appears on the gauge to be tested as shown in Fig. 1.53.

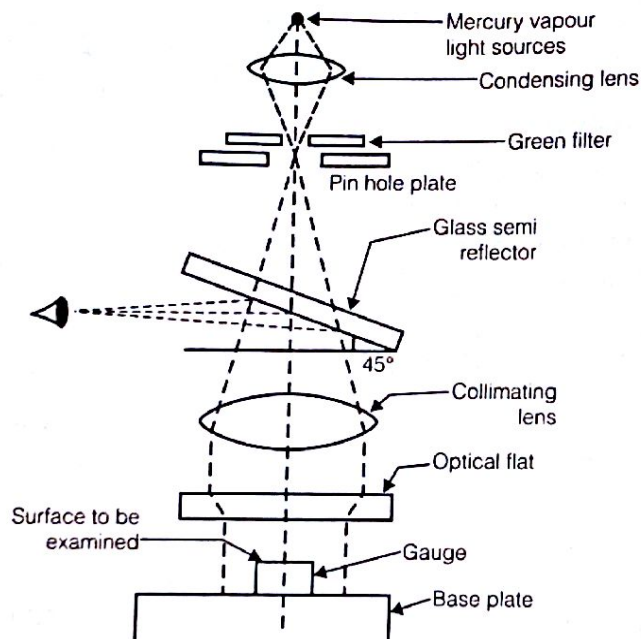


Fig. 1.52 : Interferometer

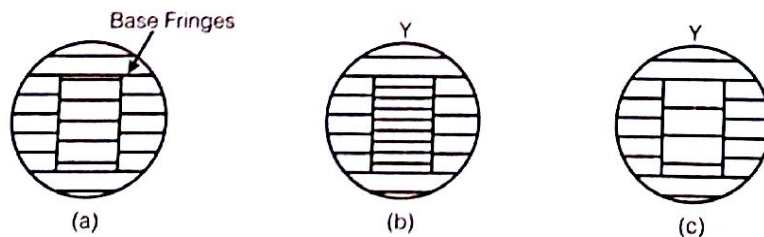


Fig. 1.53 : Fringe pattern on different surfaces

If the fringe appears parallel and symmetric as shown in Fig. 1.53 (a), it means that gauge surface is flat and parallel to base plate of interferometer. When fringes on the gauge are either more or less spaced, it means that gauge is at an angle from the base plate.

1.18 STRAIGHTNESS

It is defined as the deviation of surface from ideal straight line. This straightness can be measured in 3 ways.

1. **Straight edge** : Straight edge is a piece of block of which one surface is exactly straight. By keeping this surface on the machine part under investigation, the amount of light coming from the other side is being observed. If very small amount of light is coming from the interface, it means measured surface is straight.

2. **Spirit level :** Surface under examination is divided into number of segments equal to the size of spirit level. Spirit level is there kept from one segment to another and position of bubble in it is noted down. The deviations of bubble from the center position are recorded. Spirit is used in it due to its low viscosity.
3. **Autocollimator :** As shown in Fig. 1.54 the reflector of autocollimator is moved on the surface and the deviations $\delta\theta$ are recorded in terms of $\Delta S = 2f\delta\theta$. Hence the characteristic can be plotted on the paper. By joining first and last point, a straight line can be formed and the deviations of the surface from this ideal straight line can be noted down.

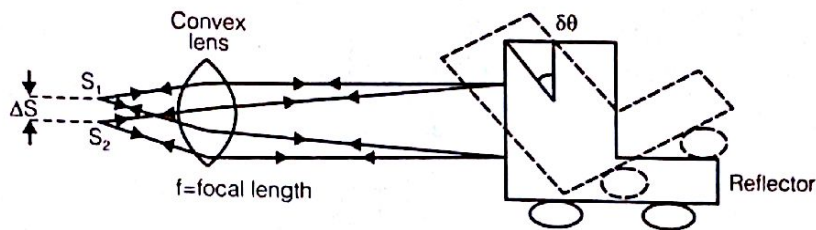


Fig. 1.54 : Autocollimator

1.19 FLATNESS

Flatness is defined as the departure of surface from ideal flat surface. Initially autocollimator or spirit level is moved along 3 different directions AB, BC and CA as shown in Fig. 1.55. These movements will identify 3 reference points A, B and C. Through these points a plane can be defined. Now autocollimator is now move practically in all the possible directions and characteristic of surface is noted down. The deviation of surface from the reference plane is called flatness.

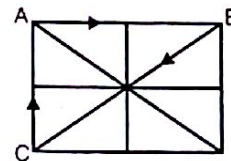


Fig : 1.55 : Movement of autocollimator over surface

1.20 COMPARATOR •

Comparators are used for measuring the dimensions from a reference value. This datum is generally established using slip gauges. To maintain precision in the measurement comparators are not allowed to move large distances.

Mechanical comparators : The characteristics of mechanical comparators are:

- (a) Usually cheaper than the other devices
- (b) Does not require any external power supply to operate.
- (c) Accuracy in inspection is independent of accuracy in manufacturing different linkages.
- (d) Usually it has linear scale.
- (e) More moving linkages which bring down the accuracy.
- (f) Range of the instrument is limited.
- (g) Due to the inertia of moving linkages makes the comparator sensitive to machine vibrations.

1.20.1 Sigma Comparators

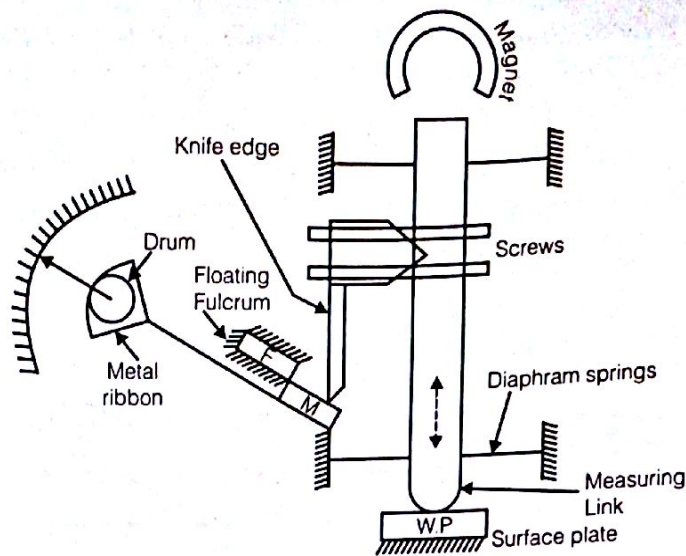


Fig. 1.56 : Sigma Comparator

Helical springs are not used in metrological instruments because residual stresses develop in the spring during deflection and it takes time for the system to come back to its original position. So diaphragm springs with C-slots are used as restoring device. These springs are in the form of a sheet and C-slots are being provided so that if any amount of residual stress develops, it is relieved. As shown in Fig. 1.56 measuring link is connected with a knife edge to have a point contact. This edge resets over moving part of floating fulcrum. This ensures a positive contact between link and fulcrum and on the other side of which there is metal ribbon and a drum rotates over this ribbon due to the variations of this ribbon. Due to the variation of size of work pieces, measuring link will move up and down which will make the cylinder over ribbon to rotate and this results in the deflection of pointer. A magnet is placed above the link to have uniform pressure over it. By the movement of link an attractive force will develop between the magnet and measuring link and upon removing the work piece, sudden jerk will not appear over it.

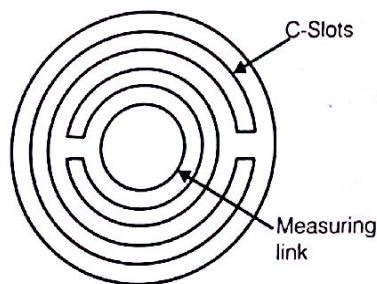


Fig. 1.57 : Diaphragm Spring

1.20.2 Mikrokator

A thin metal strip is given left hand twist on one side and right hand twist on the other. The central portion will remain neutral. As shown in Fig. 1.58 due to pivot, movement of the measuring link

converts into horizontal increment of the twisted spring. Due to that right hand side of the spring is either twisted more or twisted less. Due to this imbalance in the twist causes the central portion to rotate and the deflection can be noted down. The functions of the magnet here is similar to sigma comparator. The twisted spring is perforated all along its length so that if any amount of residual stresses appears it will be relieved.

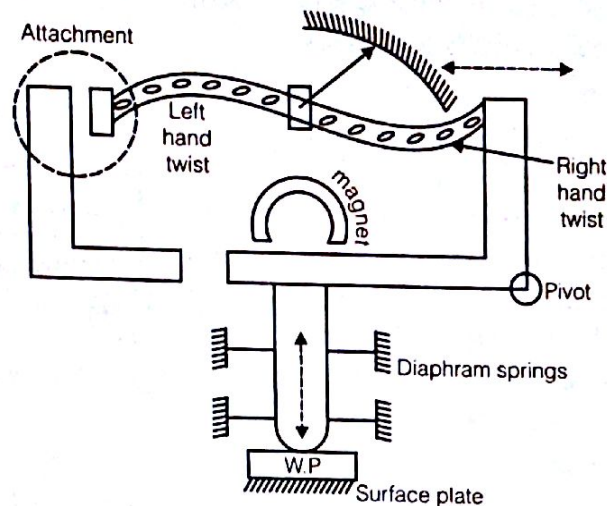


Fig. 1.58 : Mikroktor

1.20.3 Pneumatic comparators

Pneumatic comparators work on the principle that of an air jet. Upon decreasing the stand-off distance, the pressure on the back ground of jet will increase. This pressure is called back pressure and can be directly related to the measurement. These comparators can be further be divided into three types :

1. Flow type :

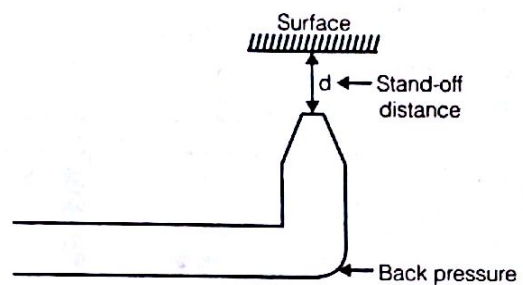


Fig. 1.59 : Principle of an airjet

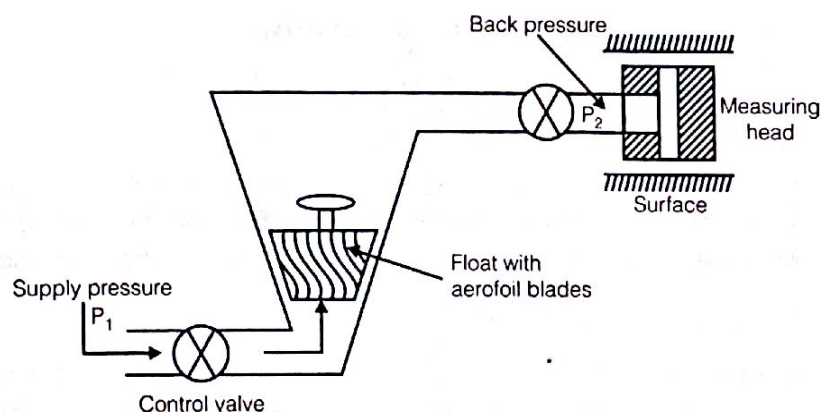


Fig. 1.60 : Rotameter

The design of head is decided by the geometric feature under measurement. As shown in Fig. 1.60 depending upon distance there will be back pressure ' P_2 ' and the difference between $(P_2 - P_1)$ decides the position of the float. This float is having aerofoil shape blades so that due to the flow of air it rotates. If it is stationary, it will stick to the wall of rotameter and due to static friction between float and tube, the system will become insensitive to small change in back pressure ' P_2 '. The tube is slightly tapered to maintain linear relationship in the measurement because air is compressible.

2. Differential type

This comparator is used to compare the two surface i.e. which surface is at a higher level and which is lower. Two pressure streams P_1 and P_2 does not mix with each other as shown in bellow. One stream goes inside the bellow and other remains on the outer surface. Depending upon the position of bellow from the neutral position it can be known that which surface is higher and which is lower.

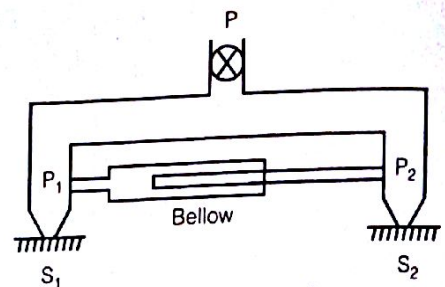


Fig. 1.61 : Differential type

3. Back pressure type

As shown in Fig. 1.62 the back pressure readings can be noted down from the manometer and it can be expressed by the following equation:

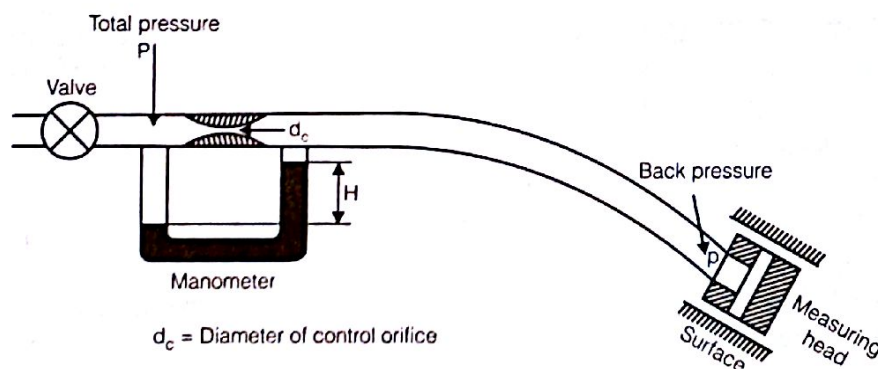


Fig. 1.62 : Back pressure type

$$\frac{p}{P} = A - b \left(\frac{M}{C} \right) \quad \dots(1)$$

The moment jet is completely closed, the back pressure will be slightly higher than the total pressure P (as shown in characteristic curve in Fig 1.63). This curve is linear between 0.6 to 0.8. So pneumatic comparators are used only in this range. So from equation (1)

$$0.6 = 1.1 - \frac{b}{C} M_{\max} \quad \dots(2)$$

$$0.8 = 1.1 - \frac{b}{C} M_{\min} \quad \dots(3)$$

or

$$\frac{b}{C} M_{\max} = 0.5$$

$$\frac{b}{C} M_{\min} = 0.3$$

Dividing these equations

$$\frac{M_{\max}}{M_{\min}} = \frac{5}{3} \quad \dots(4)$$

Subtracting 1 from both the sides of this equation

$$\frac{M_{\max}}{M_{\min}} - 1 = \frac{5}{3} - 1$$

$$M_{\max} - M_{\min} = \text{Range} = \frac{2}{3} M_{\min} \quad \dots(5)$$

Adding 1 on both sides of equation (4)

$$\frac{M_{\max}}{M_{\min}} + 1 = \frac{5}{3} + 1$$

$$M_{\max} + M_{\min} = \frac{8}{3} M_{\min}$$

Dividing by 2

$$M_{\text{avg}} = \frac{4}{3} M_{\min} = 2 \text{ Range}$$

Differentiating equation (1) we get

$$\frac{dp}{dM} = -\frac{b}{C} P \quad \dots(6)$$

Taking average of (2) and (3) we get

$$0.7 = 1.1 - \frac{b}{C} M_{\text{avg}}$$

$$\text{So } \frac{b}{C} = \frac{0.4}{M_{\text{avg}}} \quad \{\text{putting this value in equation (6)}\}$$

$$\frac{dp}{dM} = -\frac{0.4P}{M_{\text{avg}}}$$

This is called pneumatic sensitivity. It is directly proportional to total pressure. So sensitivity of comparator will be better when total pressure is higher. But larger total pressure requires large size manometer which may not be suitable for ergonomics point of view. For small pressures, since it takes some time for the signal to reach manometer, it may be lost due to compressibility of air. So manometers are placed as close to measuring head as possible.

The overall magnification is defined as output divide by input. So

$$\text{Magnification} = \frac{dR}{dI} = \frac{dR}{dp} \times \frac{dp}{dM} \times \frac{dM}{dI}$$

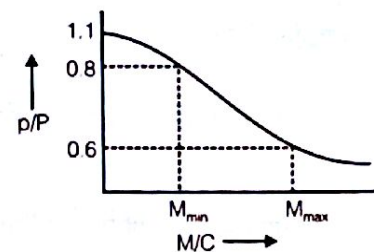


Fig. 1.63 : Characteristic equation of pneumatic comparator

$$\frac{dR}{dp} = \text{Indicator sensitivity}$$

$$\frac{dp}{dM} = \text{Pneumatic sensitivity}$$

$$\frac{dM}{dl} = \text{Measuring head sensitivity}$$

Sensitivity is vector so '-' or '+' sign will come but magnification factor is scalar. If d_c is control orifice diameter and d_m is measuring head then :

$$C = \text{Area of control orifice} = \frac{\pi}{4} d_c^2$$

$$M = \text{Measuring head area} = \pi d_m l$$

It is the cross section area through which compressed air is coming in contact with atmosphere.

Example : 1.16

The characteristic equation for a pneumatic comparator is represented by $\frac{p}{P} = 1.1 - 0.5 \left(\frac{M}{C} \right)$.

The curve is linear in the range of $\frac{p}{P} = 0.6$ to 0.8 . The diameter of control orifice is 0.5 mm and diameter of measuring orifice is 1 mm. If indicator sensitivity is 30 mm per 1 kN/m², determine

1. Range of linear measurement
2. Overall magnification of comparator if the total pressure behind control orifice is 3 bar.

Solution :

1. The characteristic equation of pneumatic comparator is

$$\frac{p}{P} = 1.1 - 0.5 \left(\frac{M}{C} \right)$$

Putting the linear range in the equation we get

$$0.6 = 1.1 - 0.5 \left(\frac{\pi d_m l_{\max}}{\frac{\pi}{4} d_c^2} \right) \quad \dots(1)$$

$$0.8 = 1.1 - 0.5 \left(\frac{\pi d_m l_{\min}}{\frac{\pi}{4} d_c^2} \right) \quad \dots(2)$$

where

$$d_m = 1 \text{ mm}$$

$$d_c = 0.5 \text{ mm}$$

Hence we get the linear range as

$$l_{\max} - l_{\min} = 0.025 \text{ mm}$$

$$2. \text{ Indicator sensitivity} = \frac{dR}{dP} = \frac{30 \times 10^{-3}}{1000} \frac{M}{N/m^2}$$

$$= 30 \times 10^{-6} M/N/m^2$$

Measuring head sensitivity

$$\frac{dM}{dl} = \pi d_m = \pi \times 1 \times 10^{-3} M$$

Pneumatic sensitivity

$$\frac{dp}{dM} = \frac{0.4P}{M_{av}}$$

$$= \frac{0.4 \times 300 \times 10^3}{\pi \times 10^{-3} \left\{ \frac{l_{max} + l_{min}}{2} \right\} \times 10^{-3}} \because M_{av} = \pi d_m \left\{ \frac{l_{max} + l_{min}}{2} \right\}$$

$$= \frac{2400}{\pi} \times 10^9 N/m^4$$

$$\text{Overall magnification} = \frac{dR}{dp} \times \frac{dp}{dM} \times \frac{dM}{dl}$$

$$= (\pi \times 10^{-3}) \left(\frac{2400}{\pi} \times 10^9 \right) \times (30 \times 10^{-6})$$

$$\text{Magnification} = 72,000$$

1.21 SURFACE FINISH

A machined surface is having 2 types of irregularities i.e. roughness and waviness. Small wavelength fluctuations are called roughness (Primary texture) and large wavelength deviations are called waviness (Secondary texture). Waviness is being produced by machine vibrations, chatter, errors in guide ways etc. Roughness appears due to improper selection of cutting fluid development of temperature on rake face etc.

1.21.1 Lay and Flaw

Predominant surface patterns produced by feed marks is called Lay and the surface irregularities present which are random is known as flaw.

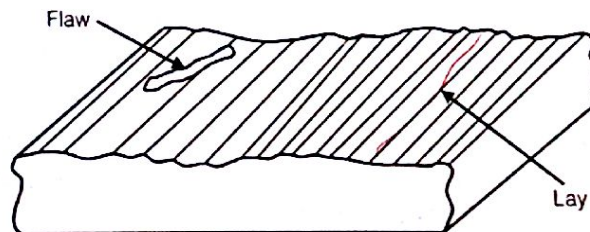
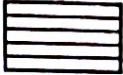
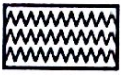


Fig. 1.64

Lay indicates the plane of projection of the view of symbol where finish is observed. The different types of lays are as under

Symbol	Diagram	Description
=		Parallel lay : Surface is produced by shaping planing etc.
⊥		Perpendicular lay : Surface is produced by shaping and planing
X		Crossed lay : Such surface can be produced by knurling operation
M		Multidirectional lay : Such surfaces are produced by grinding operation
C		Circular lay : The surfaces are produced by facing operation
R		Radial lay

1.21.2 Methods of Establishing Datum

1. **M – System** : After plotting the characteristic of any surface a horizontal line is drawn by joining 2 points. This line is shifted up and down in such a way that 50% area is below the line and 50% area is above the line. This line is called mean line which acts as a datum in the measurement.

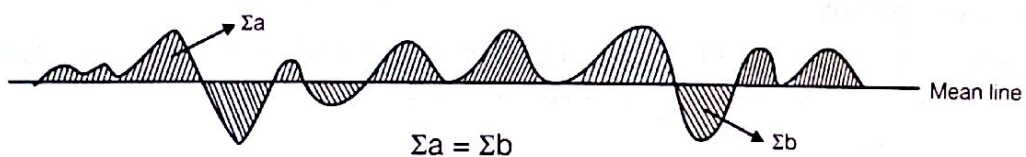


Fig. 1.65 : M-system

2. **E – System** : A sphere of 25 mm diameter is rolled over the surface and the locus of its center is being traced out called envelope. This envelope is shifted in downward direction till the area above the line is equal to the area below the line. This is called mean envelope and the system of datum is called E – System.

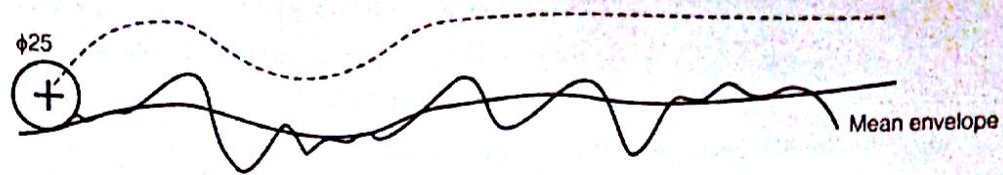


Fig. 1.66 : E-System

1.21.3 Numerical Values to Represent Surface Finish

1. **Peak to Valley height (R_t or R_{max})** : It is the difference between highest peak and deepest valley. This measurement may not give the true characteristic of any surface because due to some sudden jerk peak to valley height is high in a very small region. Otherwise the entire surface is quite all right.
2. **Center line average value (CLA, R_a)** : n number of points are taken on hills and valleys and their distance from the mean line $y_1, y_2, \dots, y_n$ is taken. Their average is called CLA value.

$$R_a = \frac{y_1 + y_2 + \dots + y_n}{n}$$

Cutoff length is one in which measurement of roughness is being carried out (or length of travel of stylus). So R_a value can also be represented as

$$R_a = \frac{\Sigma a + \Sigma b}{L}$$

Where

Σa = area above the line

Σb = area below the line

L = cutoff length

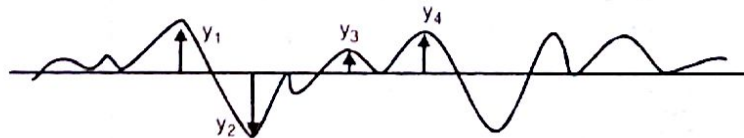


Fig. 1.67

If $y = f(x)$ is the characteristic equation of the roughness, R_a value can also be expressed as

$$R_a = \frac{1}{L} \int_0^L y dx$$

The approximate value of R_a is $\frac{H_{max}}{4}$.

Maximum height of unevenness can also be expressed as

$$H_{max} = \frac{f^2}{8R}$$

If complete tool signature is given

$$H_{max} = \frac{f}{\tan \psi + \cot \psi_1}$$

where

f = feed

ψ = side cutting edge angle

ψ_1 = end cutting edge angle

3. Root mean square value (RMS, R_g)

$$R_g = \sqrt{\frac{1}{L} \int_0^L y^2 dx}$$

4. 10 point value (R_z). It is the average of 5 highest peakes and 5 deepest valleys.

1.21.4 Representation of Surface Finish

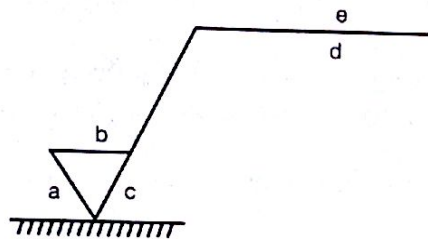


Fig : 1.68

- a : Machining allowance
- b : Roughness value
- c : Direction of lay
- d : Sampling or cutoff lengths
- e : Production method

Symbols used in drawing

Symbol	CLA value
	8 – 25 μm
	1.6 – 8 μm
	0.025 – 1.6 μm
	< 0.025 μm

1.21.5 Talysurf

Diamond point comes in contact with surface through a flexible skid for providing protection to the diamond point. As the diamond point moves up and down the position of core in the coil changes. This changes the effective resistance and it is measured by a wheat stone bridge.

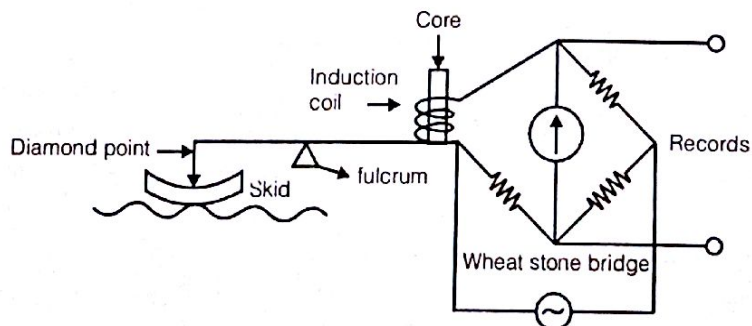


Fig. 1.69 : Principle of Talysurf

1.22 SCREWTHREAD METROLOGY

The methods of measuring different parameters of screw thread are give as under :

1. Major diameter :

- (a) External Micrometer
(c) Optical Projector

- (b) Bench Micrometer
(d) Tool Makers Microscope

2. Minor Diameter :

- (a) Optical Projector
(c) Pointed anvil Micrometer

- (b) Tool Makers Microscope

3. Pitch :

- (a) Pitch gauges

- (b) Optical Projector

4. Angle : Optical Projector

5. Pitch circle diameter (effective diameter) can be measured by 2 or 3 wire (rolles) method. These wires are lapped within 0.0025 mm. Best size wire is one which coincide at pitch circle point but it will be a rare case when the wire used is best size wire but this has very little effect on the accuracy of measurement 3 wire method is used when pitch is very large 2 wires are held together as shown in Fig 1.70 d_w is the diameter of wire and it can be seen from Fig. 1.70 and 1.71 that :

$$\begin{aligned} T &= M - 2d_w \\ \text{PCD} &= T + 2CD \\ CD &= OC - DO \\ DO &= OB - DB \end{aligned}$$

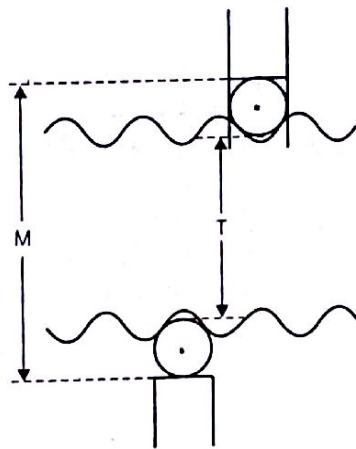


Fig. 1.70 : Two wire method

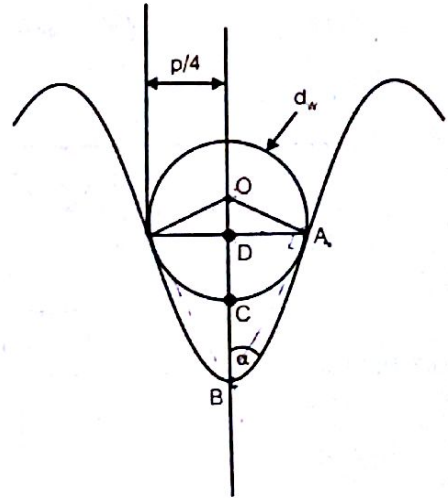


Fig. 1.71 : Calculation of effective diameter

$$\begin{aligned}\Delta ADB \quad \frac{P/4}{DB} &= \tan \alpha \\ DB &= \frac{P}{4} \cot \alpha \\ \Delta OAB \quad \frac{OA}{OB} &= \sin \alpha \\ \frac{d_w/2}{OB} &= \sin \alpha\end{aligned}$$

$$\text{So } OB = \frac{d_w}{2} \operatorname{cosec} \alpha$$

$$\text{So } DO = \frac{d_w}{2} \operatorname{cosec} \alpha - \frac{p}{4} \cot \alpha$$

$$OD = \frac{d_w}{2} - \left(\frac{d_w}{2} \operatorname{cosec} \alpha - \frac{p}{4} \cot \alpha \right)$$

$$OD = \frac{d_w}{2} (1 - \operatorname{cosec} \alpha) + \frac{p}{4} \cot \alpha$$

So effective diameter is

$$PCD = T + d_w (1 - \operatorname{cosec} \alpha) + \frac{p}{2} \cot \alpha \quad \checkmark$$

For best size wire from ΔOAD we get

$$d_w = \frac{p}{2} \sec \theta$$

Example : 1.16

While measuring the effective diameter of an external metric screw thread gauge of 3.5 mm pitch, a 30.5 mm diameter cylindrical standard and 2 mm diameter wires were used. The micrometer reading over the standard and wire was 13.3768 mm. The corresponding reading over the thread gauge and wire was 12.2428 mm. Calculate thread gauge effective diameter.

Solution :

Wire over cylindrical standard

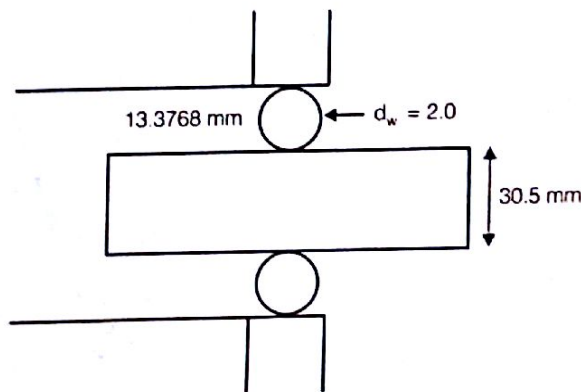


Fig. 1.72

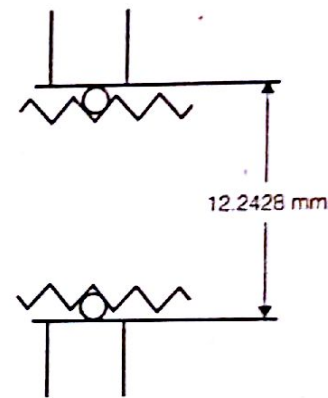


Fig. 1.73

$$d_w = 2.0 \text{ mm}$$

$$\text{pitch} = 3.5 \text{ mm}$$

Since micrometer are used with some attachments correction factor must be considered to calculate the exact dimension. So from cylindrical standard are know that

$$\begin{aligned} \text{Correction} &= (2.0 + 30.5 + 2.0) - 13.3768 \\ &= 21.1232 \text{ mm} \end{aligned}$$

Actual value of m over thread gauge is

$$m = 33.366 \text{ mm}$$

$$T = m - 2 d_w$$

$$= 33.366 - 2 d_w$$

$$T = 29.366 \text{ mm}$$

$$PCD = T + d_w(1 - \operatorname{cosec} \alpha) + \frac{p}{2} \cot \alpha$$

Since it is metric thread and for metric thread

$$2\alpha = 60^\circ, \quad \alpha = 30^\circ$$

So

$$PCD = 29.366 + 2(1 - \operatorname{cosec} 30) + \frac{3.5}{2} \cot 30$$

$$PCD = 30.39 \text{ mm}$$

1.23 ACCEPTANCE TESTS

These tests are performed on the machine before inducing it for mass production. These tests are of two types :

1. **Dynamic Test :** Tests carried out over the machine in working condition. A work piece shown in figure is machined at 3 different places. Its diameter is equal to $1/8^{\text{th}}$ of length. To adopt the machine in mass production machined portion should be cylindrical and error should not exceed 0.02 mm in 300 mm.

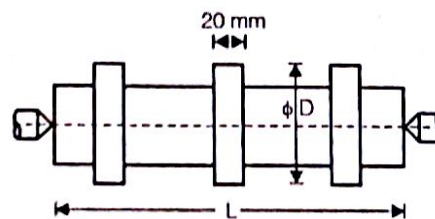


Fig. 1.74 : Test piece for practical tests on a lathe machine

2. **Static Test :** These tests will be discussed for 3 machines namely lathe, milling and drilling.

(a) Acceptance test for lathe

(i) Is bed true?

The bed of the machine should be flat and to check it its surface is divided into segments and the segment size equal to the size of spirit level. Now the spirit level is kept from segment to segment to check flatness.

(ii) Is spindle true?

Work is held on the spindle so its axis should be parallel to bed. A mandrel is fitted into the spindle and properly centered. A dial gauge fixed over the carriage with its plunger touching the mandrel as shown in Fig. 1.75. By moving carriage towards spindle, if the axis is parallel there should not be any variation in dial gauge. It is not possible to have these errors zero. So there errors should not exceed beyond a certain value. These errors are permissible in upward direction and towards the tool.

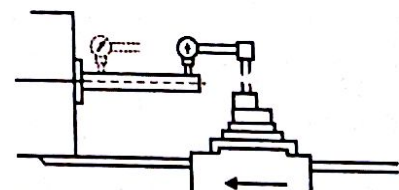


Fig. 1.75 : Spindle axis parallel to bed

(iii) Is line of centre is parallel to spindle axis?

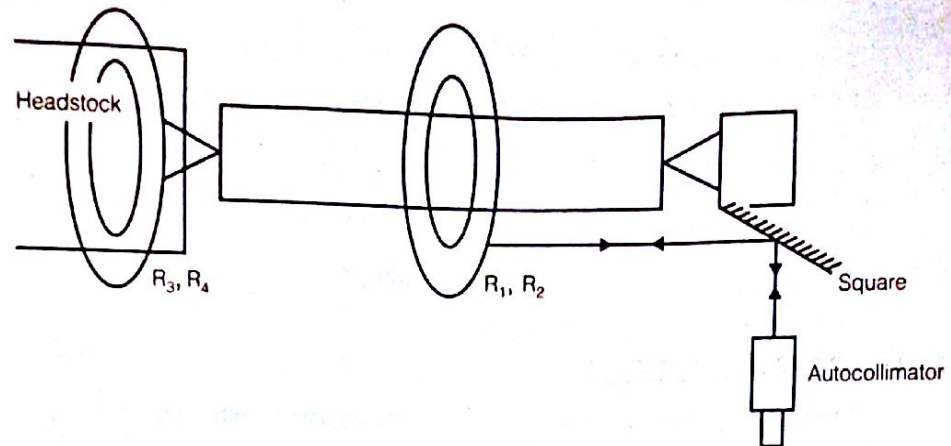


Fig. 1.76 (i) : Work axis parallel to spindle axis (1st test)

Reflector of the autocollimator is initially fitted over the work piece and the autocollimator readings are taken with 180° phase difference i.e. R_1 and R_2 . Later on the reflector is placed over the spindle and the same experiment was repeated. If both axes are parallel to each other, the autocollimator readings will match. The same test can be performed by placing mandrel between head stock and tailstock as shown in Fig.1.76 (ii).

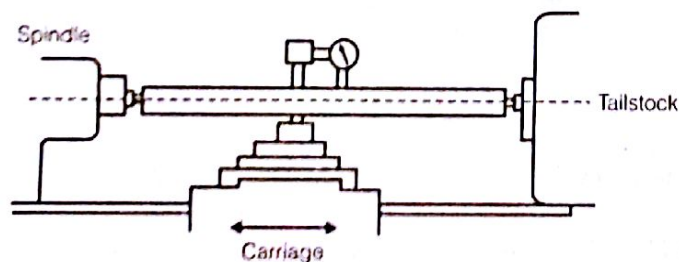


Fig. 1.76 (ii) : Work axis parallel to spindle axis (IInd test)

(iv) Whether cross slide movement is perpendicular?

Perpendicularity of cross slide is important because tool post is mounted over it. A straight edge is placed in the spindle. The plunger of dial gauge is touching on one side of straight edge and base is mounted on the cross slide. By the movement of cross slide pointer will move over the straight edge. If cross slide movement is perpendicular, there will not be variation in the dial gauge.

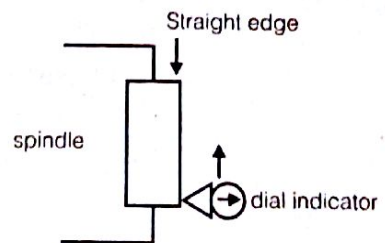


Fig. 1.77 : Cross slide perpendicular to spindle axis

(v) Whether tailstock quill movement parallel to bed?

The test is carried out in similar fashion as the spindle movement parallel to bed.

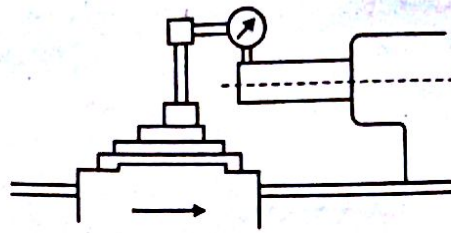


Fig. 1.78 : Tailstock quill

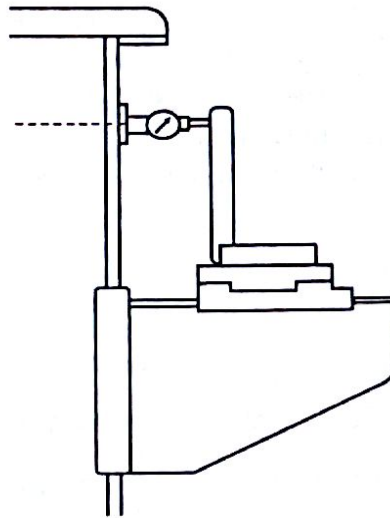
(b) Acceptance test of Milling**(i) Whether table surface square with the vertical movement?**

Fig. 1.79 : Testing squareness of table surface

A square is clamped on the table as shown in Fig. 1.79 the dial gauge base is fixed over the arbor with pointer touching one side of square. By giving vertical motion to the table, the variation in dial gauge should be within some permissible limits.

(ii) Whether table movement is parallel to cutter axis?

Base of the dial gauge is fixed over the arbor and plunger touching the table of milling machine. By giving table biaxial movement the variation on the dial gauge should be within permissible limits.

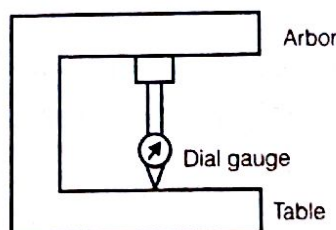
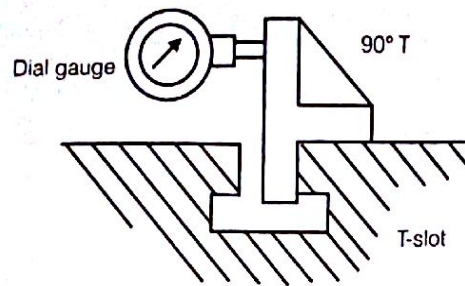
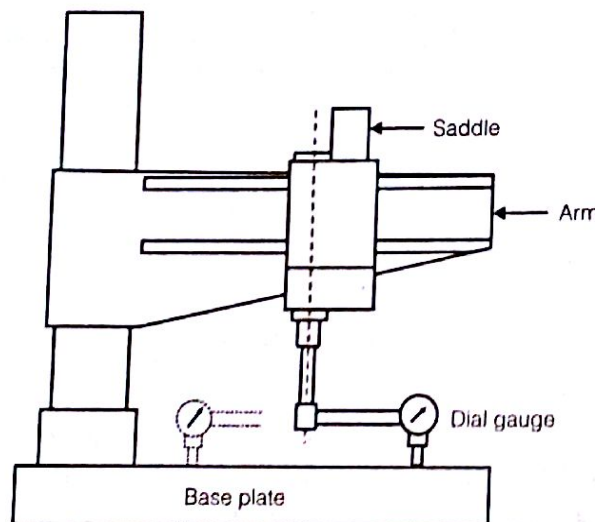


Fig. 1.80 : Table movement is parallel to arbor

(iii) Accuracy of Central T-slot?**Fig. 1.81 : Central T-slot is perpendicular**

Accuracy of the slot is important because machining fixtures are clamped in the central T-slot. A T is inserted in the T slot as shown in Fig. 1.81. The dial gauge is mounted over its surface with base fixed over the arbor. By giving vertical movement to table there should not be any variation in the dial gauge.

(c) Acceptance tests for radial drilling machine**(i) Whether saddle and arm movement is parallel to base plate?****Fig. 1.82 : Saddle and arm movement parallel**

The base of the dial gauge is kept over the saddle and initially by giving movement to the saddle, dial gauge variations are noted down. In the second set arm movements are given by fixing the saddle.

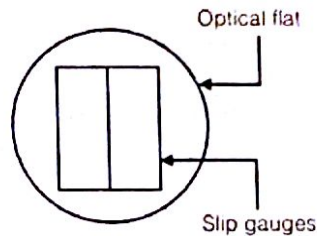
(ii) Whether spindle feed movement is square with the base?

A mandrel is fitted in the spindle. The base of dial gauge is fixed over the base plate with plunger touching the mandrel. By giving spindle vertical movement deviation in the dial gauge is noted down. If there is no variation in the dial gauge, it means spindle axis is perpendicular to base plate.

OOOO

PRACTICE QUESTIONS

- A ring gauge is used to measure
 - Outside diameter but not roundness
 - Roundness but not outside diameter
 - Both outside diameter and roundness
 - Only external threads
- Two slip gauges of 10 mm width measuring 1.000 mm and 1.002 mm are kept side by side in contact with each other lengthwise. An optical flat is kept resting on slip gauge as shown in the figure. Monochromatic light of wavelength 0.00058928 mm is used in the inspection. The total number of straight fringes that can be observed on both slip gauges is



- 2
 - 6
 - 8
 - 13
- What is the dominant direction of the tool marks or scratches in a surface texture having a directional quality called?
 - Primary texture
 - Secondary texture
 - Lay
 - Flaw
 - A component requires a hole which must be within the two limits of 25.03 mm and 25.04 mm which of the following statement about the reamer size are correct
 - Reamer size cannot be below 25.03 mm
 - Reamer size cannot be above 25.04 mm
 - Reamer size can be 25.04 mm
 - Reamer size can be 25.03 mm
 Select the correct answer using the code given below
 - 1 and 3
 - 1 and 2
 - 3 and 4
 - 2 and 4
 - GO and NO-GO plug gauges are to be designed for a hole $20.000^{+0.050}_{+0.010}$ mm gauge tolerance can be taken as 10% the hole tolerance following ISO design of gauge design, sizes of GO and NO - GO will be respectively
 - 20.010 mm and 20.050 mm
 - 20.014 mm and 20.046 mm
 - 20.006 mm and 20.054 mm
 - 20.014 mm and 20.054 mm

max. or min. ?
 - In strain gauge dynamometers the use of how many active gauge makes the dynamometers more effective
 - Four
 - Three
 - Two
 - One

7. Match List-I (Measuring device) with List-II (Parameter measured) and select the correct answers using the codes given below the list:

List-I

- A. Diffraction grating flat Surface
- B. Optical flat
- C. Auto Collimators
- D. Laser scan of micrometer

List-II

- 1. Small angular deviations
- 2. Online Measurement of Moving Parts
- 3. Measurement of Gear pitch
- 4. Joining hydraulic Piston rod for Agriculture Machinery
- 5. Taper of any surface

Codes:

	A	B	C	D
(a)	5	4	2	1
(b)	3	5	1	2
(c)	3	5	4	1
(d)	5	4	1	2

8. Consider the following statement A nomenclature $50H_8P_8$ denotes that

- (1) hole basic size is 50mm
- (2) it is shaft basis system
- (3) 8 indicates fundamental deviation

Which of the statements given above are correct

- (a) 1, 2 and 3
- (b) 1 and 2 only
- (c) 1 and 3 only
- (d) 1 only

9. The value of surface roughness 'h' obtained during turning operation at a feed f with a round nose tool having a radius 'r' is given as

- (a) $f/8r$
- (b) $f^2/8r$
- (c) $f^3/8r$
- (d) $f^3/8r^2$

10. A threaded nut of M 16, ISO metric type, having 2 mm pitch with a pitch diameter of 14.701 mm is to be checked for its pitch diameter using two or three number of balls or rollers of following size

- (a) rollers of 2 mm ϕ
- (b) rollers of 1.155 mm ϕ
- (c) balls of 2 mm ϕ
- (d) balls of 1.155 mm ϕ

11. which one of the following is a clearance fit

- (a) $\phi H50^{+0.015}_{+0.005} h50^{-0.010}_{+0.000}$
- (b) $\phi H50^{+0.015}_{+0.010} h50^{+0.025}_{+0.015}$
- (c) $\phi H50^{-0.015}_{+0.000} h50^{+0.025}_{+0.005}$
- (d) $H50^{-0.010}_{-0.000} h50^{+0.030}_{+0.005}$

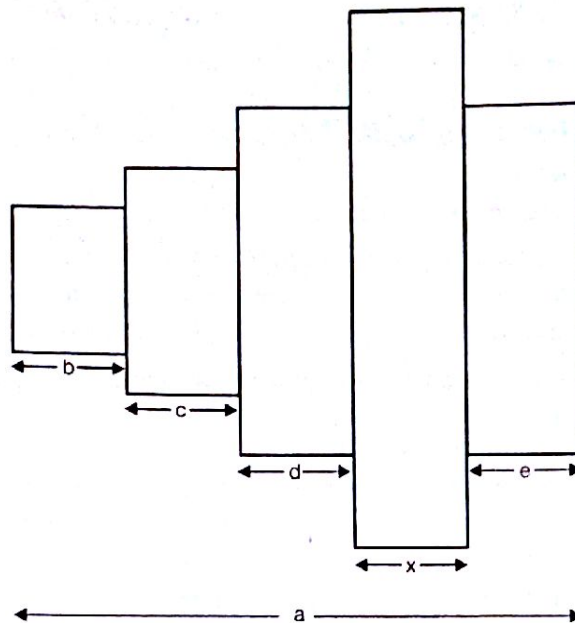
12. In tolerance specification 25 D 6 the letter D represents

- (a) gauge of tolerance
- (b) upper deviation
- (c) lower deviation
- (d) type of fit

13. what symbol is used to indicate surface roughness

- (a) =
- (b) $\sqrt{\quad}$
- (c) 0.1
- (d) ∇

14. $a_{-0.001}^{+0.005}$ $b_{-0.01}^{+0.01}$ $c_{-0.003}^{-0.002}$ $d_{-0.001}^{-0.0}$ $e_{0.0}^{+0.005}$ X will have the following tolerance



- (a) $X_{-0.007}^{+0.018}$ (b) $X \pm 0.0125$
(c) $X_{-0.014}^{+0.019}$ (d) $X_{+0.005}^{-0.012}$
15. The M and E systems in metrology are related to measurements of
(a) Screw thread (b) flatness
(c) angularity (d) surface finish
16. A hole is specified as $40_{+0.000}^{+0.050}$ mm the mating shaft has a clearance fit with minimum clearance 0.01 mm the tolerance on shaft is 0.04 the maximum clearance in mm between hole and shaft is
(a) 0.04 (b) 0.05
(c) 0.10 (d) 0.11
17. Tolerances are specified
(a) to obtain desired fits
(b) because it is not possible to manufacture a size exactly
(c) to obtain higher accuracy
(d) to have proper allowances
18. Optical flats are made of
(a) quartz (b) glass
(c) plastic (d) steel
19. Repeatability of measuring equipment is
(a) the closeness with which a measurement can be read directly from a measuring instrument
(b) difference between measured value and actual value
(c) the smallest change in measurand that can be measured
(d) the capability to indicate the same reading again and again for a given measurand

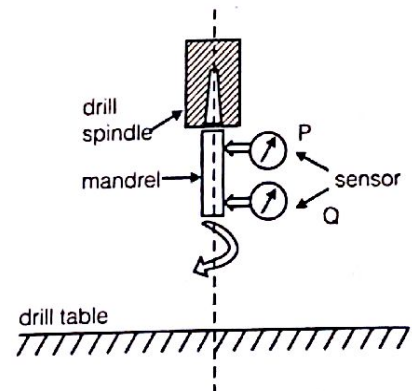
20. External taper can be accurately measured with the help of
 (a) sine bar and slip gauges (b) dividing head
 (c) precision balls and height gauge (d) combination set
21. A sine bar is specified by
 (a) its total length
 (b) the centre distance between the two rollers
 (c) the size of the rollers
 (d) the distance between rollers and upper distance
22. Surface plate is usually made of grey cast iron because it provides
 (a) non wearing plate (b) very hard plate
 (c) easy to cast plate (d) lubrication due to graphite flakes
23. What are the upper and lower limits of the shaft represented by $60 f_8$?

Use the following data :

Diameter 60 lies in the diameter step of 50-80 mm.

Fundamental tolerance unit, i , in mm = $0.45 D^{1/3} + 0.001 D$, where D is the representative size in mm; Tolerance value for IT8 = $25i$. Fundamental deviation for 'f' shaft = $-5.5 D^{0.41}$

- (a) Lower limit = 59.924 mm, Upper Limit = 59.970 mm
 (b) Lower limit = 59.954 mm, Upper Limit = 60.000 mm
 (c) Lower limit = 59.970 mm, Upper Limit = 60.016 mm
 (d) Lower limit = 60.000 mm, Upper Limit = 60.046 mm
24. A displacement sensor (a dial indicator) measures the lateral displacement of a mandrel mounted on the taper hole inside a drill spindle. The mandrel axis is an extension of the drill spindle taper hole axis and the protruding portion of the mandrel surface is perfectly cylindrical. Measurements are taken with the sensor placed at two positions P and Q as shown in the figure. The readings are recorded as R_x = maximum deflection minus minimum deflection, corresponding to sensor position at X, over one rotation. If $R_P = R_Q > 0$, which one the following would be consistent with the observation?
- (a) The drill spindle rotational axis is coincident with the drill spindle taper hole axis.
 (b) The drill spindle rotational axis intersects the drill spindle taper hole axis at point P.
 (c) The drill spindle rotational axis is parallel to the drill spindle taper hole axis.
 (d) The drill spindle rotational axis intersects the drill spindle taper hole axis at point Q.



25. A shaft has a dimension, $\phi 35^{+0.009}_{-0.025}$. The respective values of fundamental deviation and tolerance are
 (a) $-0.025, \pm 0.008$ (b) $-0.025, 0.016$
 (c) $-0.009, \pm 0.008$ (d) $-0.009, 0.016$

ANSWERS

METROLOGY

1. (c)	2. (d)	3. (c)	4. (b)	5. (d)	6. (b)	7. (b)
8. (d)	9. (b)	10. (b)	11. (a)	12. (c)	13. (d)	14. (c)
15. (d)	16. (c)	17. (b)	18. (a)	19. (d)	20. (a)	21. (b)
22. (a)	23. (a)	24. (c)	25. (d)			

Material Science

All the dead species in the universe are called matter. Material science is a combination of solid state physics and solid state chemistry. The elements are divided into categories like metals, nonmetals, polymer and ceramics.

2.1 METALS

Metal is one which has free electrons. These materials has their characteristic appearance and they are capable of changing shape upon machining and gives good finish. At room temperature they are usually solid and to some extent they are malleable and ductile. Metals are good conductors of heat and electricity e.g. Copper, Silver, Gold etc.

2.2 NON-METALS

The materials in the right portion of the periodic table are called non-metals. These materials are usually dull in appearance, brittle and poor conductor of electricity (except graphite). They does not form alloys but combine chemically to form compounds.

2.3 ORGANIC POLYMER

The long molecules are composed of structural entities called 'mer' which are successively repeated along the chain. All organic polymers are based on C-C bonding. Polymers are mostly amorphous and sometimes partly crystalline. The term polymer means many 'mers'. It is in coil form i.e. continuous series of C-C atom. If ethylene (C_2H_4) which is a gas, is subjected to some temperature and pressure with some initiator (to break the double bond) it transform into polyethylene.

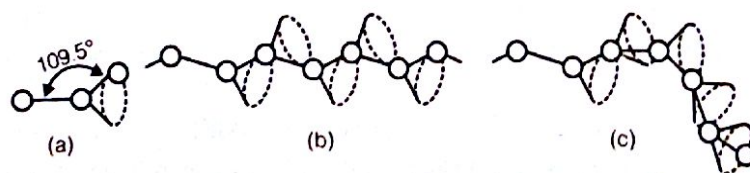


Fig. 2.1 : (Schematic representations for how polymer chain shape is influenced by the positioning of Carbon Atoms)

It is also called long chain molecule or macromolecule. Diamond is also a C-C bond and it is the hardest element. It is the phenomenon of conformation which makes the polymers so soft, when a single polymer chain can take different 3D shapes, it is called conformation. It can be seen from Fig. 2.2 that because of bond rotation (conformation) there is considerable increase in strain with slight increase in stress.

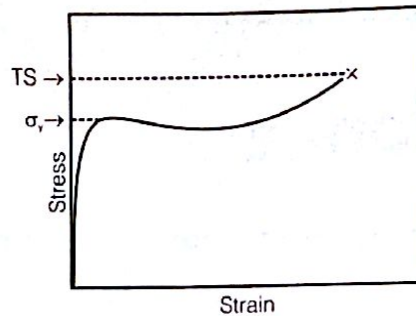


Fig. 2.2 : (Schematic stress-strain curve for a plastic polymer)

The degree of polymerization is referred as the number of mers in a polymer chain.

$$\text{DOP} = \frac{\text{Molecular weight}}{\text{mer weight}}$$

The degree of crystallization is referred as

$$f_c = \frac{\text{Volume of crystalline region}}{\text{Total volume of the specimen}}$$

The packing is more dense in crystalline part

Let ρ_c is the density of crystalline part and ρ_a is the density of amorphous part, so the density of polymer sample is

$$\rho V = \rho_a V_a + \rho_c V_c$$

$$\Rightarrow \rho \left(\frac{V_c}{V_a} + 1 \right) = \rho_a + \rho_c \frac{V_c}{V_a}$$

$$\rho(1 + f_c) = \rho_a + \rho_c f_c$$

$$\rho = \frac{\rho_a + \rho_c f_c}{1 + f_c}$$

The plastic is defined as the organic polymer that can be easily shaped. It can be further divided into thermoplastic and thermosetting plastics. Thermoplastics softens when heated and becomes hard when cooled. The process can be repeated many times. Thermosetting plastics once shaped cannot be recycled. Upon heating they get burned but does not melt. It is because of cross linking between adjacent molecular chains.

Polyvinyl chloride (PVC), Polypropylene (PP), Polyethylene (PE) and Polystyrene (PS) plastics are known as BIG-4 because 70-80% of market is covered by these plastics only. Other well known thermoplastics are poly tetra fluoro ethylene (PTFE or TEFLON), acrylic etc. The commonly used thermosetting plastics are Epoxy, Polyester, Phenol formaldehyde (Bakelite) etc. Most of these thermosetting plastics are used as matrix in composite materials.

2.4 CERAMICS

Ceramics are burnt in earth and its definition can be given in a negative way i.e. whatever is not a metal, non-metal and organic polymer is called a ceramic. The properties of ceramic are:

1. They are extremely brittle
2. High thermal stability
3. High chemical stability (corrosion resistance)
4. High hardness

The most important ceramics are silica and alumina. Silica (SiO_2) has a 3D structure that is generated when every corner oxygen atom in each tetrahedron is shared by adjacent tetrahedra. If these tetrahedras are arranged in an ordered manner (crystal form) it is called quartz.

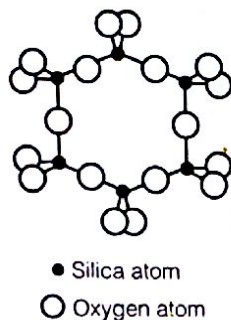


Fig. 2.3 : Structure of Quartz

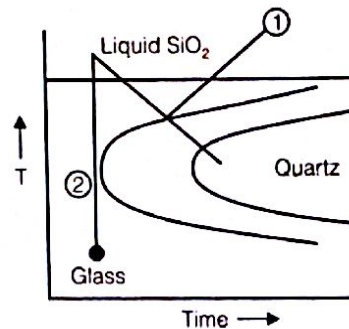


Fig. 2.4 : (TTT Diagram of SiO_2 cooling)

Upon Cooling liquid silica at a very slow rate (along line 1 in Fig. 2.4) crystals being formed (Quartz). It is used in making optical flat and also has application in watches. Upon cooling liquid silica at a very fast rate (along line 2) the viscosity of liquid increases as temperature decreases and finally the material becomes solid even though there are no crystals in it (Fig. 2.5). This is called amorphous silica or glass. It is an unstable state and after some time it converts into crystalline form. This is called devitrification of glass. Upon quenching liquid metals at a very fast rate (10^6 °C/sec) the metal will also convert into glass called metallic glass and is used in transformer cores to minimize the eddy current losses. Since the ceramic is extremely brittle, its failure is because of the propagation of crack. **In the larger samples the probability of having larger cracks are more so their strength in tension is less.** So the strength of ceramics is size dependent. In compression the failure is not there because of the propagation of crack, hence their strength is more in compression.

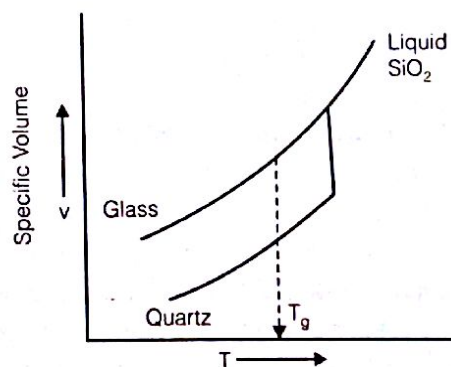


Fig. 2.5 : (Specific volume versus-temperature behaviour of crystalline and non crystalline materials)

Upon quenching liquid silica the viscosity of liquid increases and there is a temperature at which it is difficult to understand whether it is liquid or solid. This is called **glass transition temperature (T_g)**. This temperature is unique and it depends on the cooling rate. Faster the cooling rate T_g will be higher. $[\text{SiO}_4]^{-4}$ is a building block for glass and quartz. If the atoms are arranged in a periodic hexagonal structure (Fig. 2.3), it is called quartz. If the atoms are randomly oriented (Fig. 2.6), it is called glass or fused silica. Since $[\text{SiO}_4]^{-4}$ building block is having a long chain, hence the operating temperature of pure silica glass is very high. These glasses are used in high temperature application e.g. furnace window etc. To break this long chain, SiO_2 is mixed with Na_2O and CaO which acts as a catalyst.

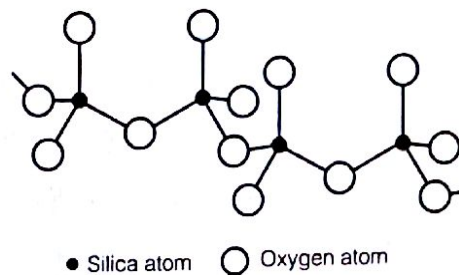


Fig. 2.6 : Structure of Glass

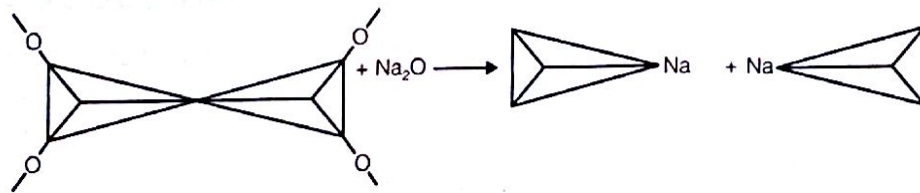


Fig. 2.7 : Soda lime glass

Na_2O acts as a network modifier and the length of silica tetrahedra chain decreases which decreases in the operating temperature. This glass is called soda lime glass. Glass fails by fracture. To increase its strength, the propagation of crack is made difficult by introducing compressive stresses in the outer layer by the following methods:

1. **Thermal tempering or air quenching :** This process involves heating of glass upto softening temperature and then quenching in cool air medium. The outer layer of the glass, quickly becomes rigid but the core remains still hot. When core comes to room temperature its specific volume decreases and it tries to pull the material from the surface towards the core. This introduces compressive stresses in the outer layer.
2. **Ion exchange :** In this process, the glass is dipped into a KNO_3 bath at suitably high temperature. The Na^+ ions are replaced out by K^+ ions and since K^+ are bigger in size the outer layer tries to expand but the core resists the motion of outer layer. This induces compressive stresses in the outer layer. The stresses generated is much higher (**approximately 400 MPa**) but the thickness of compressive layer is much smaller than in tempering. The tempered glass are also called as toughened glass and upon fracture it gives large number of small pieces with blunt edges. Ceramic or glass if loaded at a certain load, it may take that load for some time but it fails at the same load after some time. This phenomenon of ceramics is called **static fatigue**.

2.5 CRYSTAL STRUCTURES OF CERAMICS

2.5.1 AX-Type Crystal Structures of Ceramics

There are equal numbers of cations and anions. These are often referred to as AX compounds, where A denotes the cation and X the anion. Perhaps the most common AX crystal structure is the **sodium chloride (NaCl)**, or rock salt, type. The coordination number for both cations and anions is 6. A unit cell for this crystal structure (Fig. 2.8) is generated from an FCC arrangement of anions with one cation situated at the cube center and one at the center of each of the 12 cube edges.

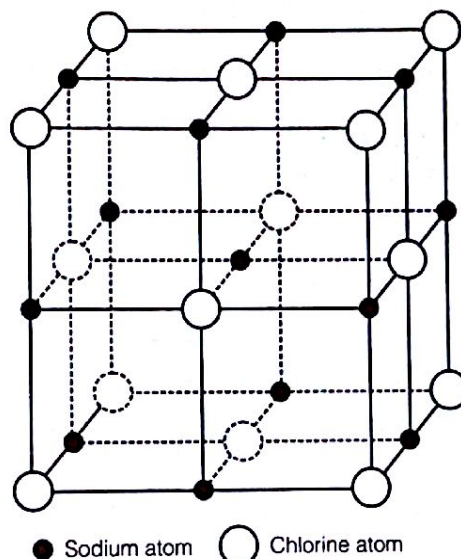


Fig. 2.8 : A unit cell for the rock salt or sodium chloride (NaCl) crystal structure

2.5.2 Cesium Chloride Structure

Fig. 2.9 shows a unit cell for the cesium chloride (CsCl) crystal structure the coordination number is 8 for both ion types. The anions are located at each of the corners of a cube, whereas the cube center is a single cation. Interchange of anions with cations, and vice versa, produces the same crystal structure. This is not a BCC crystal structure because two different kinds of ions are involved.

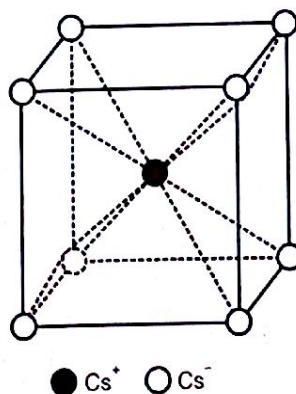


Fig. 2.9 : A unit cell for the cesium chloride (CsCl) crystal structure

2.5.3 Zinc Blende Structure

The coordination number is 4 and all ions are tetrahedrally coordinated.

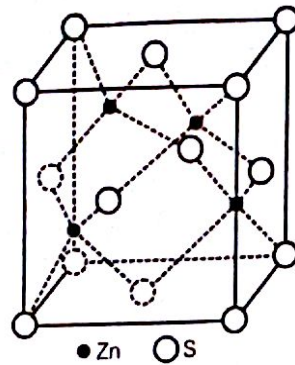


Fig. 2.10 : (A unit cell for the zinc blende (ZnS) crystal structure)

2.5.4 A_mX_p -Type Crystal Structures

If the charges on the cations and anions are not the same, compound ions exist with the chemical formula A_mX_p and such structure is found in fluorite (CaF_2). Calcium ions are positioned at the centers of cubes, with fluorine ions at the corners.

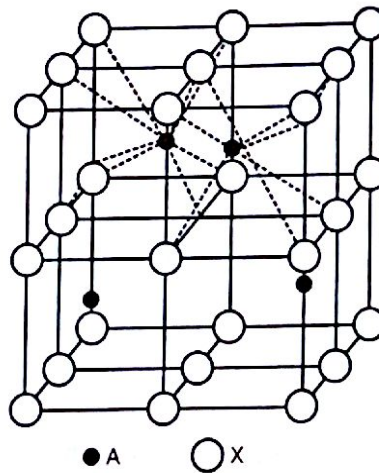


Fig. 2.11 : A unit cell for the fluorite (A_mX_p) crystal structure

2.5.5 $A_mB_nX_p$ -Type Crystal Structures

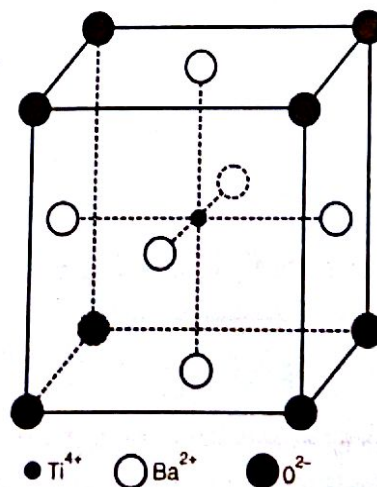


Fig. 2.12 : A unit cell for the $A_mB_nX_p$ type crystal structure

It is also possible for ceramic compounds to have more than one type of cation; for two types of cations (represented by A and B), their chemical formula may be designated as $A_m B_n X_p$. Barium titanate ($BaTiO_3$), having both Ba^{2+} and Ti^{4+} cations, falls into this classification.

2.6 COMPOSITE MATERIALS

Composite materials are made to take advantage of different properties of metal, polymer and ceramics. These materials are manufactured by the combination of 2 or more materials. In composite materials there is a matrix (compatible binder) and a reinforcing material. The strength of composite is generally in between matrix and reinforced material but sometimes it is even higher than the pure matrix and pure fibres. The composite materials are generally classified according to the type of matrix or the orientation of fibres.

Classification of composite Based on Matrix :

Polymer matrix composite : When an organic polymer e.g. epoxy, phenolic resin etc. is used as matrix material, the composite is called polymer composite. In this category, the two most important composites are **glass fiber reinforced plastic (GFRP)** and **carbon fiber reinforced plastic (CFRP)**. GFRP is having high strength but low stiffness and it is used in sports equipments, filament rocket motor cases, pressure vessels, aircraft components etc.

Ceramic matrix composite : A typical example of this composite is RCC column. As discussed before, that ceramics are very weak in tension and bending but have excellent compressive strength and stability at high temperature, it is generally reinforced with steel to increase its load carrying capacity. The reinforcement is done at a section close to the bottom because this surface (bottom) is subjected to tensile stress and steel can withstand that. By increasing the fibre content in the composite, its strength and fracture, toughness increases.

Metal matrix composites : In these composites, there is a matrix of any ductile material e.g., Al, Mg, Ti etc., These composites can operate at higher temperature than other composites. The main properties include increase in specific strength, creep resistance, dimensional stability etc.

Classification of Composites based upon the shape of reinforcement :

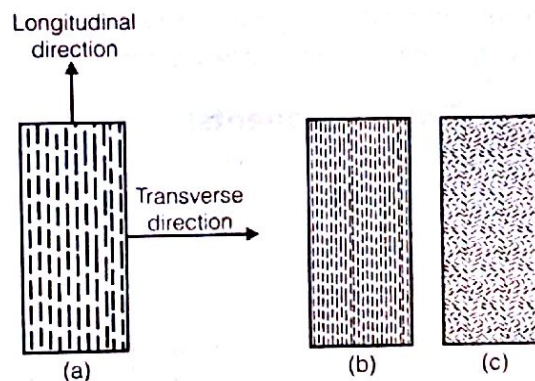


Fig. 2.13 : (a. Continuous and aligned, b. discontinuous and aligned, and c. discontinuous and randomly oriented fiber-reinforced composites.)

2.7 PHASE DIAGRAMS

Phase diagrams are important and essential tools to understand compositional concentrations of two or more elements. It is a plot of all temperature composition space showing the stability of various phases. In other words what will be the melting point of alloy that can be understood from the phase diagram.

Terminology used in phase diagram :

System : The substances that are isolated and unaffected by their surrounding are called as system.

State : It is the physical condition of the system and is governed by the quantities such as pressure, temperature.

Property : The quantity that govern the state of system. Intensive properties are independent of mass. While extensive properties are mass dependent. **OR** Characteristic of a system is known as property.

Components : Compounds that constitute a system.

Phases : Physically distinct, chemically homogeneous and mechanically separable substances.

Equilibrium : This is the state of a system at any specified condition when the system possesses minimum free energy.

Degree of freedom : The number of independent variables required to describe the state of a system are called as the degree of freedom.

Constraint : A system that has zero degree of freedom is said to be constraint.

Gibb's Phase Rule

$$F = C - P + 2$$

where,

F = degree of freedom

C = no. of components

P = no. of phases

The degree of freedom decreases when number of phases increases. A two component system cannot have more than 4 phases. **Based on number of components phase diagram is divided as :**

2.7.1 Unary phase diagram

It is mainly used to show the phase diagram of carbon or any other pure material. Graphite at 3000 K and 125 bar pressure converts into diamond. There is very limited practical utilities of such diagrams plotted between temperature and pressure axis like water.

2.7.2 Binary phase diagram (Two components)

These diagrams are further divided into 3 categories.

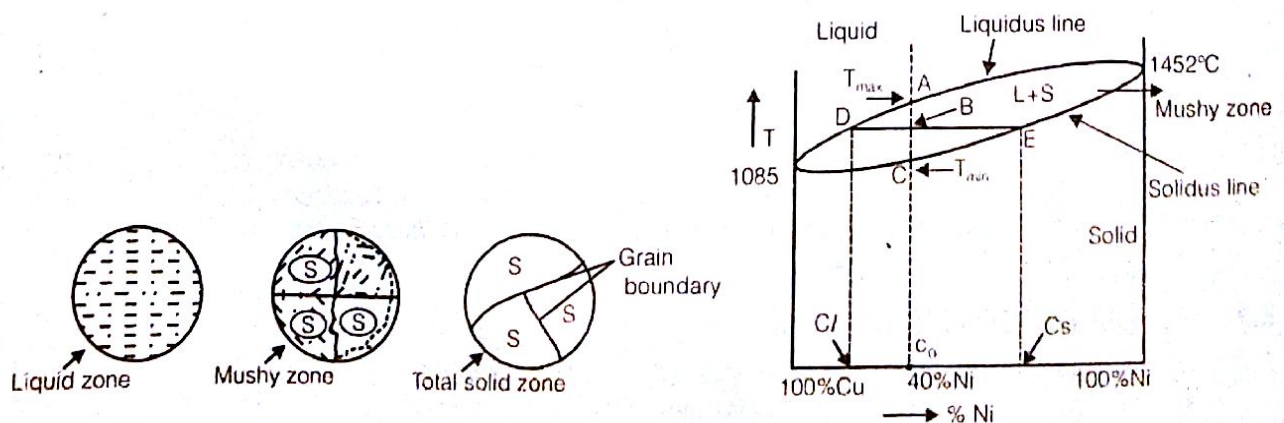
2.7.2.1 The materials which are completely soluble in the liquid as well as solid state.

Fig. 2.14 : (Cu - Ni phase diagram)

In the above phase diagram the line which separates the liquid phase with that of mushy zone is called liquidus. The line which separates the mushy zone with solid phase is called solidus. On such phase diagram solidification takes place over a range of temperature. It can be seen in the diagram that by decreasing the temperature from points 'A' to point 'C' mass fraction of solid increases. Let m_s and m_l be the mass fraction of solid and liquid phase at point B. C_l and C_s are the percentage of Ni in the liquid and solid phase.

$$m_l C_l + m_s C_s = C_0$$

and

$$m_s + m_l = 1$$

$$m_l C_l + (1 - m_l) C_s = C_0$$

We get

$$\Rightarrow m_l = \frac{C_s - C_0}{C_s - C_l}$$

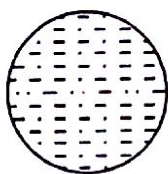
$$m_s = \frac{C_0 - C_l}{C_s - C_l}$$

This is called lever rule.

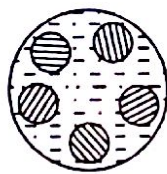
Binary phase diagrams are plotted at a particular pressure, so purposefully we are restricting one degree of freedom, so in case of binary phase diagram Gibbs phase rule converts into

$$F - 1 + P = C + 2 - 1$$

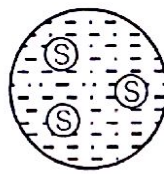
$$F + P = C + 1$$



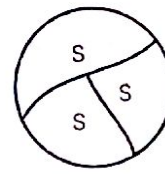
(a)



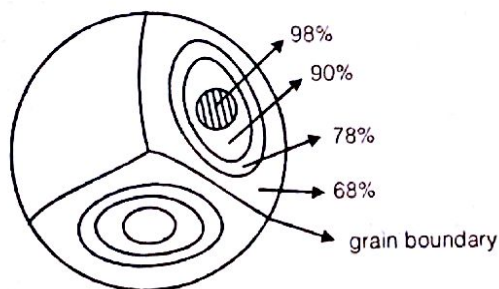
(b)



(c)



(d)



(e)

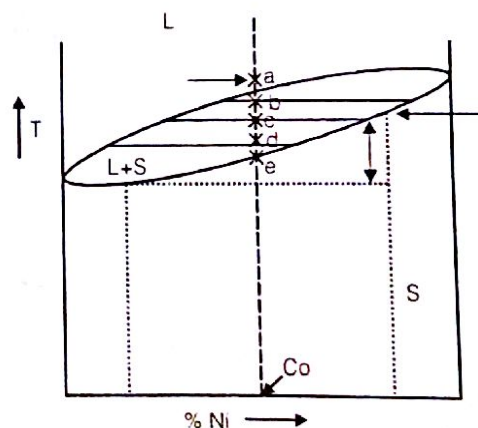


Fig. 2.15 : Cu-Ni phase diagram and coring

As shown in figure upon cooling the Cu-Ni sample (with $C_0\%$ of Ni) along line a-e following transformations were observed. As soon as the temperature of the sample decreases slightly below the liquidus line to point 'b', nucleation will start at number of places. Upon decreasing the

temperature to 'c' or 'd' mass fraction of solid phase will keep on increasing. It can be seen from the phase diagram that by decreasing the temperature within the mushy zone the % of Ni within the solid phase keeps on decreasing. If the cooling is slow (or) equilibrium cooling of Ni will diffuse from the centre to the outward direction making the solid phase homogeneous. This happens by the process of diffusion and for every 20°C increase in temperature diffusion gets doubled.

Upon cooling the same sample rapidly since there is no sufficient time for the diffusion to take place, the centre of the solid phase will have higher percentage of Ni and in the outward direction % of Ni will keep on decreasing (as shown in Fig. 2.15). It is observed that at the grain boundary % of Ni in the material will be low which will have lower melting point. Upon hot working the material, grain boundary will liquify producing micro cracks with in the material. This phenomenon is called coring or miscibility gaps. It can be avoided by heat treatment.

2.7.2.2 Binary phase diagram of a Type-II

The material which are completely soluble in the liquid state but partially soluble in the solid state (Eutectic phase diagrams) :

The binary phase diagram of type-II is called Eutectic phase diagram (in Latin the word, Eu means nice, and tectic means melting). One of the important diagram in this category is that of Pb-Sn.

α phase is the solid solubility of tin in lead and β phase is the solid solubility of lead in tin. There appears a point at which liquid converts into two different solids. This reaction is called eutectic reaction. This reaction is invariant in nature and appears at particular temperature and composition.

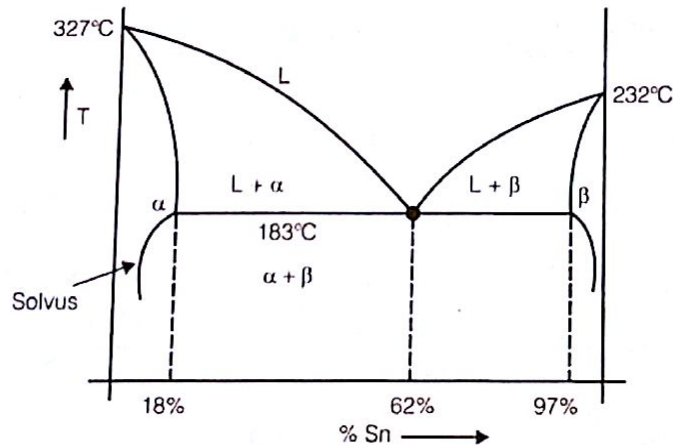
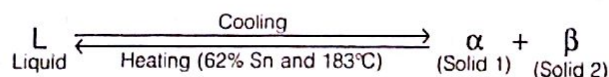


Fig. 2.16 : Pb-Sn phase diagram



At eutectic point degrees of freedom are zero. So by changing parameter, the eutectic point disappears. So from Gibb's phase rule,

$$F + P = C + 1$$

$$0 + P = 2 + 1$$

$$P = 3$$

So there are three phases which exists i.e. α , β , L at eutectic point.

Example : 2.1

Determine the mass fraction of the phases present at 184°C in a sample of lead and tin with 45% Sn in it.

Solution :

$$m_{\alpha} = \frac{62 - 45}{62 - 18}$$
$$= \frac{17}{44} = 0.38$$
$$m_I = \frac{45 - 18}{62 - 18}$$
$$= 1 - m_{\alpha} = 0.62$$

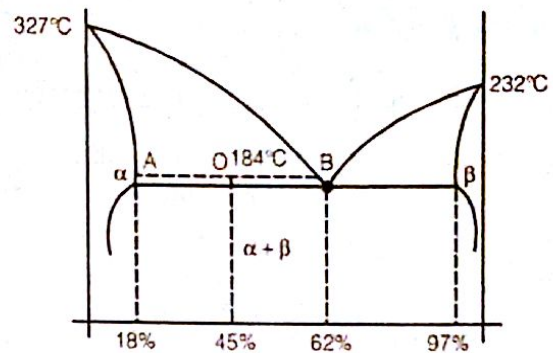


Fig. 2.17

Example : 2.2

Determine the mass fraction of the phases present at 182°C in the sample of Sn and Pb with 45% Sn in it.

Solution :

$$\begin{aligned} m_{\alpha} &= \frac{97-45}{97-18} \\ &= 0.6582 \\ m_{\beta} &= \frac{45-18}{97-18} \\ &= 1 - m_{\alpha} \\ &= 0.3418. \end{aligned}$$

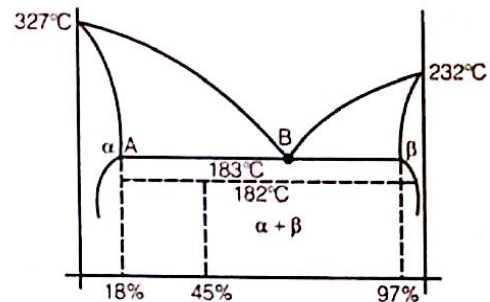


Fig. 2.18

Example : 2.3

Determine the mass fraction and volume fraction of phases present in an alloy at Pb-Sn with 40% Sn at 100°C. At this temperature 10% Sn can be dissolved in Pb and 2% Pb can be dissolved in Sn. The densities of Pb and Sn at this temperature are 11.23 and 7.24 g/cc respectively.

Solution :

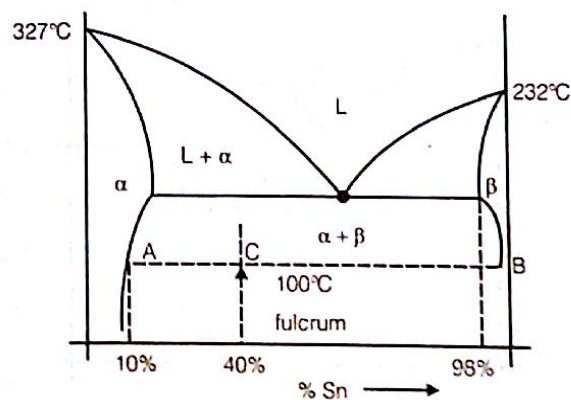


Fig. 2.19

From the above figure

$$m_{\alpha} = \frac{98 - 40}{98 - 10} = 0.659$$

$$m_{\beta} = 0.340$$

Before calculating the volume fraction, the density of α and β has to be calculated

$$\frac{100}{\rho_{\alpha}} = \frac{10}{\rho_{sn}} + \frac{90}{\rho_{pb}} \quad \text{So, } \frac{100}{\rho_{\alpha}} = \frac{10}{7.24} + \frac{90}{11.23}$$

and

$$\frac{100}{\rho_{\beta}} = \frac{98}{\rho_{sn}} + \frac{2}{\rho_{pb}} \quad \text{So, } \frac{100}{\rho_{\beta}} = \frac{98}{7.24} + \frac{2}{11.23}$$

So

$$\rho_{\alpha} = 10.64 \text{ g/cc}$$

and

$$\rho_{\beta} = 7.29 \text{ g/cc}$$

volume fraction of α

$$v_{\alpha} = \frac{\frac{m_{\alpha}}{\rho_{\alpha}}}{\frac{m_{\alpha}}{\rho_{\alpha}} + \frac{m_{\beta}}{\rho_{\beta}}}$$

$$= \frac{\frac{0.659}{10.64}}{\frac{0.659}{10.64} + \frac{0.34}{7.29}} = \frac{0.0019}{0.0619 + 0.0466} = 0.57(57\%)$$

$$v_{\beta} = 1 - v_{\alpha} \\ = 0.43(43\%)$$

2.7.7.3 Binary Phase Diagram of Type-III

The materials which are completely soluble in the liquid state and completely insoluble in the solid state. Alloys of Bi follows these type of diagrams.

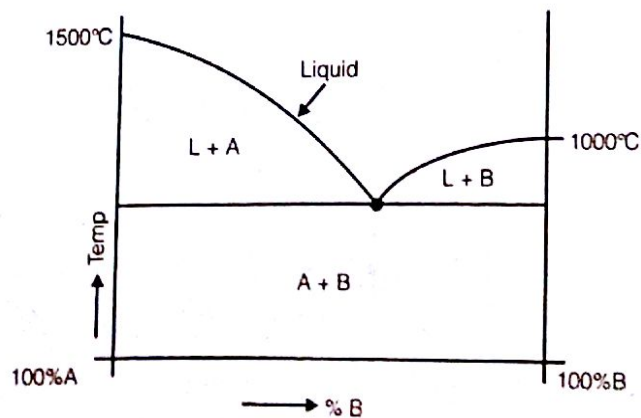


Fig. 2.20

2.8 EXPERIMENTAL METHODS OF CONSTRUCTING PHASE DIAGRAMS

2.8.1 Thermal Analysis Allotropy

One of the indication of phase change is that there will be latent heat transactions at a particular temperature and a horizontal line will appear over temperature and time graph.

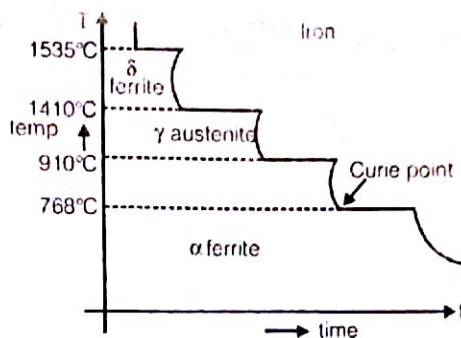


Fig. 2.21 : Allotropy of Iron

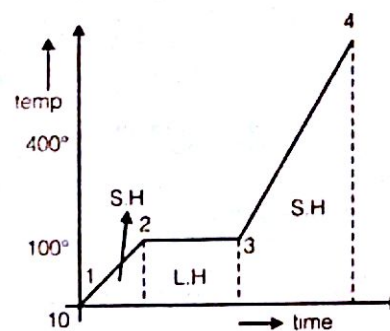


Fig. 2.22 : Phase Change of Water

For example, water converts into another phase steam by consuming latent heat at 100°C. (Fig. 2.22). Similarly there are four horizontal lines on temperature Vs time graph of iron as per shown is figure Fig. 2.21. Phase means physically distinct matter and it was observed that at 768°C. There is no change in the micro structure and only magnetic properties are disappearing. This temperature is called curie point. In paramagnetic materials, electrons are unpaired and due to this alloy exhibit colour (copper alloys). In diamagnetic materials electrons are paired and such alloys are colourless. Iron is such a material which some time exhibit paramagnetic and some time diamagnetic. This characteristic is called "**Ferro Magnetism**".

2.8.2 Metallographic Methods

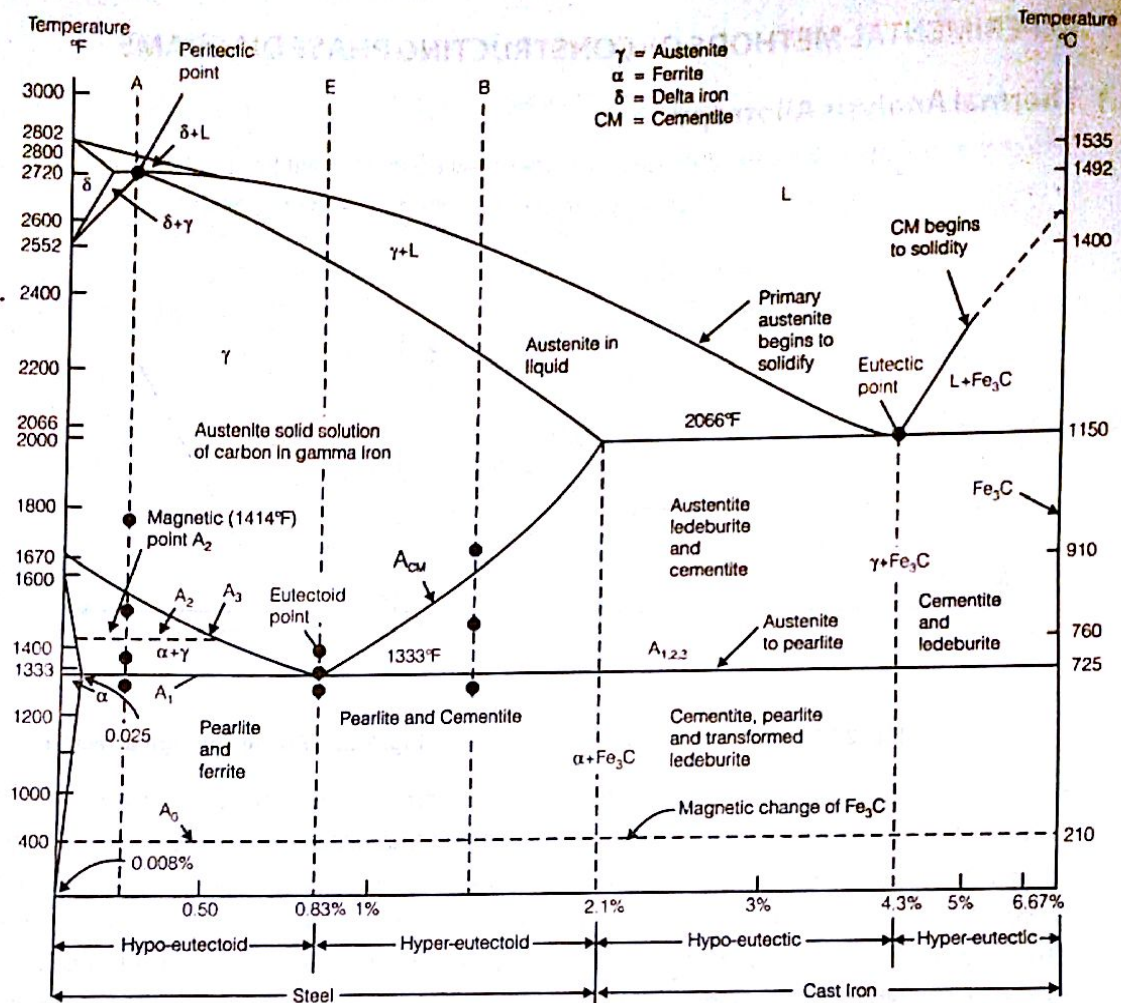
Microstructure is observed at different temperatures and different microstructure means different phase.

2.8.3 X-ray diffraction

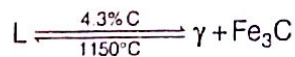
Every material is a building block of some unit cell. If the type of building block changes (or) the size of the unit cell changes, this indicates the change of phase and it can be identified by x-ray diffraction.

2.9 Fe-Fe₃C PHASE DIAGRAM

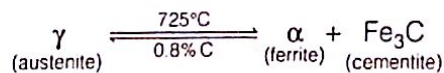
As discussed before that invariant reaction is one at which degrees of freedom are zero. Fe-C diagrams is such a diagram at which there are three invariant reactions appear.

Fig. 2.23 : Fe-Fe₃C phase diagram

1. Eutectic reaction :



2. **Eutectoid reaction :** It is a reaction when a solid phase converts into two different solid phases



725°C and 0.83% C are called eutectoid temperature and eutectoid composition respectively and at eutectoid point 3 phases will co-exist in equilibrium simultaneously. Carbon diffuses through the lattice structure and produces alternate plate of α and Fe₃C. This structure is called pearlite and it is produced by diffusion. So pearlite is not a phase, it is a phase mixture of α and Fe₃C.

3. **Peritectic reaction :** This reaction appears at 1493°C and at 0.18% C where a mixture of liquid and solid converts into another solid phase upon cooling

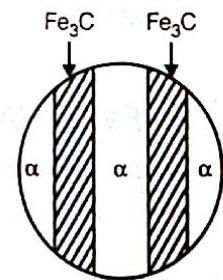
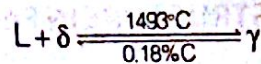
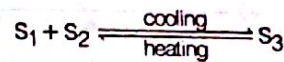


Fig. 2.24 : Diffusion of C (pearlite)



This reaction appears in alloys where there is large difference in the melting point. The phase diagram on which this reaction appears are called peritectic phase diagrams.

There is another fourth invariant reaction which does not appear on Fe-C diagram is called peritectoid reaction. When two solid phases combine together produces third solid phase upon cooling



Example : 2.4

Determine the mass fraction of phases present at $726^{\circ}C$ and with 0.4% C is an alloy of Fe_3C .

Solution :

As shown in figure γ and α phases will be present at this point. So

$$m_{\alpha} = \frac{0.8 - 0.4}{0.8 - 0.02} = 0.513 \text{ (51.3\%)}$$

$$\begin{aligned} m_{\gamma} &= 1 - 0.513 \\ &= 0.487 \text{ (48.7\%)} \end{aligned}$$

Example : 2.5

Determine the mass fraction of phases present with 0.4% C is an alloy of Fe_3C at $724^{\circ}C$.

Solution :

It can be seen in the fig that this point appears slightly below eutectoid temperature so α and Fe_3C phases will be present.

$$m_{\alpha} = \frac{6.67 - 0.4}{6.67 - 0.02} = 0.942 \text{ (94.2\%)}$$

$$\begin{aligned} Fe_3C &= 1 - 0.943 \\ &= 0.057 \text{ (5.7\%)} \end{aligned}$$

Example : 2.6

Determine the mass fraction of phases present in pearlite.

Solution :

In pearlite there is eutectoid composition, so α and Fe_3C phases will be present. The fulcrum of the line will be at the eutectoid point. So

$$\begin{aligned} m_{\alpha} &= \frac{6.67 - 0.8}{6.67 - 0.02} \\ &= 0.883 \text{ (88.3\%)} \end{aligned}$$

$$\begin{aligned} m_{Fe_3C} &= 1 - 0.883 \\ &= 0.117 \text{ (11.7\%)} \end{aligned}$$

As shown in Fe- Fe_3C phase diagram the materials upto 2.1%C are called steels and beyond that are called cast irons. The different nomenclature are marked over the phase diagram (Fig. 2.23).

2.10 DEVELOPMENT OF MICROSTRUCTURE IN Fe-C SYSTEM

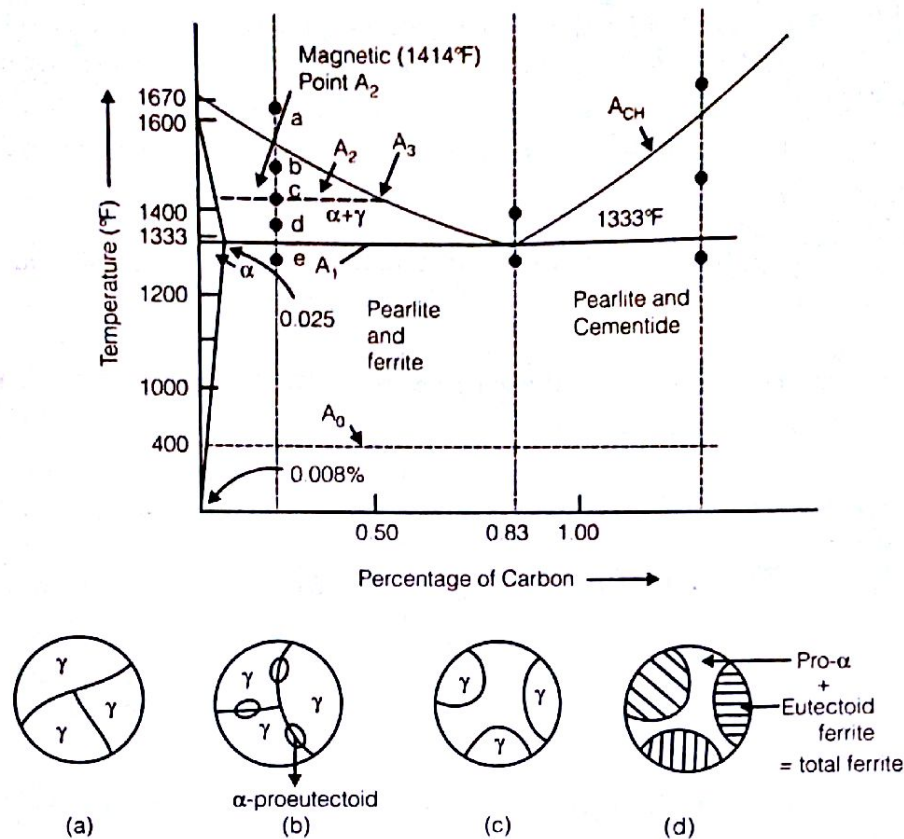


Fig. 2.25 : Development of Microstructure for Hypoeutectoid Steels

If % of Carbon in steel is equal to the eutectoid composition i.e. 0.83%, upon decreasing the temperature of the sample slightly below the eutectoid point, Austenite will convert into ferrite and cementite i.e. 0.83% carbon will bifurcate into 0.02% (ferrite) and 6.67% (cementite). This takes place by the process of diffusion. Carbon jumps from one interstitial site to another making alternate plate like structure of ferrite and cementite, this is called pearlite. If the steel sample is having composition in the hypoeutectoid region the development of micro structure along line a-d will be as follows. At point 'a' the entire structure will be austenite within the grain boundaries. Upon slightly decreasing the temperature to point 'b' ferrite will appear within the micro structure. This ferrite will be pushed towards the grain boundaries because grain boundary region has orientation mismatch. The ferrite which appears before the eutectoid temperature is called pro-eutectoid ferrite.

Upon decreasing the temperature from 'b' to 'c' following observations can be made

1. Mass fraction of pro-eutectoid ferrite increases and at point 'c' there will be canals of pro-eutectoid ferrite and the grain boundaries.
2. percentage of carbon in austenite increases and it approaches towards the eutectoid composition.

Upon slightly decreasing the temperature below eutectoid temperature austenite within grain boundaries will convert into pearlite. Only eutectoid composition produces pearlite. It can be understood from Fe-Fe₃C diagram that in the hypereutectoid region pro-eutectoid cementite (Pro-Fe₃C) will appear over the grain boundaries.

Example : 2.7

Determine the mass fraction of pro- α , eutectoid- α and total α in Fe-C alloy with 0.35% C.

Solution :

To calculate pro- α , the tie line has to be selected above eutectoid temperature

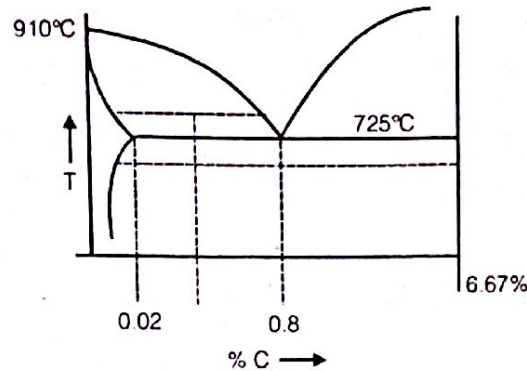


Fig. 2.26

$$M_{\text{pro-}\alpha} = \frac{0.8 - 0.35}{0.8 - 0.02} = 0.57$$

For the calculation of total- α the tie line should be selected below the eutectoid temperature

$$m_{\text{total-}\alpha} = \frac{6.67 - 0.35}{6.67 - 0.02} = 0.95$$

So

$$m_{\text{eut-}\alpha} = m_{\text{total-}\alpha} - m_{\text{pro-}\alpha} \\ = 0.95 - 0.57 = 0.38$$

Eutectoid- α is present in the microstructure of pearlite.

2.11 FAMILY OF CAST IRONS

- Gray Cast Iron :** In pure iron carbon system, if percentage of 'C' in iron increases beyond 6.67% a large amount of carbon will appear in free form (graphite pockets). This is called gray cast iron and it is used to make machine beds (to absorb small vibrations of the machine), piston rings etc.
- White Cast Iron :** Maximum solubility of carbon in iron is called white cast iron (6.67%).
- Chilled Cast Iron :** The cast iron of such composition by which it will normally freeze as gray but forced to appear as white by rapid cooling is called chilled cast iron.
- Spheroidal Cast Iron (or) Nodular Cast Iron :** These are ductile in nature. These cast irons are produced by heat treatment. Upon heat treating chilled cast iron in the presence of Mg or Ce, C combines together and comes out in the form of spheroids. These spheroids are ductile in nature.

Properties of Cast Iron	Properties of Steel
Hard (Strong)	Ductility
Good fluidity and easy to cast materials	Higher toughness
Extremely brittle	High wear resistance
Low melting point	Poor castability due to shrinkage during phase change
Good machinability defined	

2.12 EFFECT OF ALLOYING ELEMENT ON IRON

1. **Carbon** : By increasing the % of carbon, steels will slowly convert into cast irons, ductility decreases and brittleness increases as represented in stress and strain diagram.

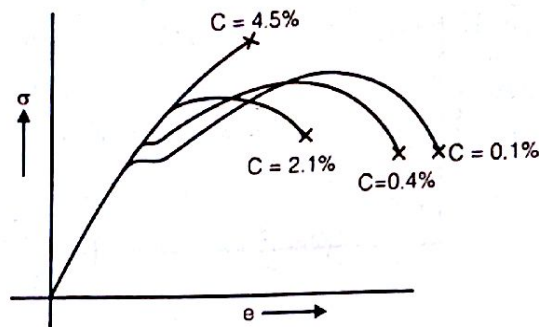


Fig. 2.27 : Stress-strain curve for different percentages of C

2. **Silicon** : The carbon equivalent can be expressed by

$$\text{C equivalent} = \% \text{C} + \frac{1}{3} \% (\text{Si} + \text{P})$$

By Addition of silicon eutectic point shifts towards left and graphite formation takes place at a much lower %age of carbon. At high temperature graphite will be in the red hot condition and due to buoyancy red hot graphite will jump over liquid iron and sparkles. This phenomenon is called kish. Apart from graphatising agent silicon also increases there hardness. Addition of silicon, helps in removing oxygen from steel castings. Such steels are called killed steels.

3. **Sulphur** : Every solid and liquid matter in the nature will have some impurity of sulphur. Sulphur after reacting with iron produces iron sulphite (FeS). FeS gets accumulated on the grain boundaries and is having lower melting point. Upon hot working the material FeS melts out producing number of cracks on the grain boundaries. As a result of that material will fail as brittle fracture. This phenomenon is called "Hot Shortness". To avoid this phenomenon 'Mn' is added into the material. "Mn" captures sulphur before it can react with iron. Also a large number of "MnS" pockets will be present in the materials. Which improves the machinability because MnS is having low shear strength. If "Mn" is around 12%, the strength of material appears to be very high called "Hadfield Steel", which is used to make bull-dozer rolls.

COMPOSITIONS				
Element	Gray iron	White iron (malleable iron)	High strength gray iron %	Nodular iron
Carbon	2.5 - 4.0	1.8 - 3.6	2.8 - 3.3	3.0 - 4.0
Silicon	1.0 - 3.0	0.5 - 1.9	1.4 - 2.0	1.8 - 2.8
Manganese	0.40 - 1.0	0.25 - 0.80	0.5 - 0.8	0.15 - 0.90
Sulphur	0.05 - 0.25	0.06 - 0.20	0.12 max	0.03 max
Phosphorus	0.05 - 1.0	0.06 - 0.18	0.15 max	0.10 max

2.13 RELATIONSHIP BETWEEN THE PHASE DIAGRAMS

When the two materials are completely insoluble solvus lines merges into the temperature axis. As the solid solubility increases solvus lines approaches towards the eutectic point and if there is complete solid solubility both the solvus lines will merge into the eutectic point to produce isomorphous phase diagrams.

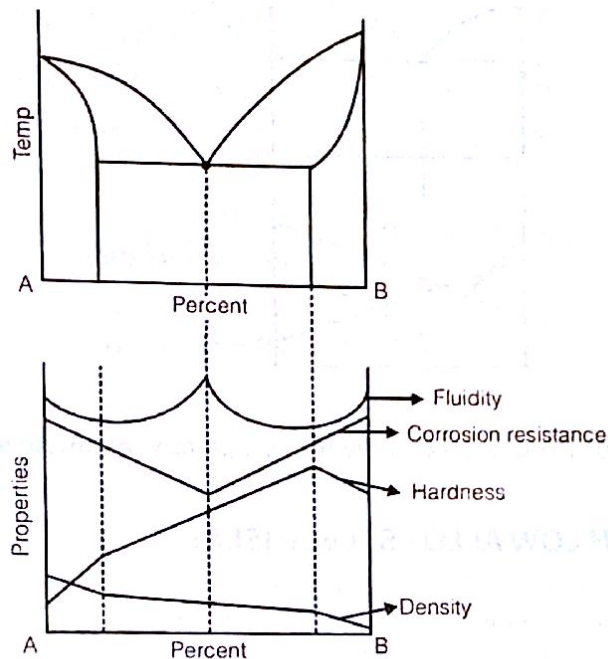


Fig. 2.28 : Properties of Material for eutectic system

1. Fluidity is maximum for pure materials and eutectics. It is directly proportional to the extent of mushy zone. Larger is the mushy zone lower will be the fluidity.
2. Corrosion resistance is very poor for eutectic composition and upon deviating from the eutectic composition, corrosion resistance increases due to the presence of pro-phase, boundaries are covered by the pro-phase.

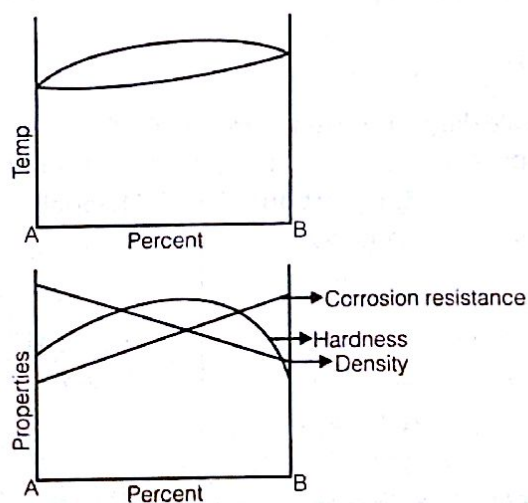


Fig. 2.29 : Properties of alloy for isomorphous system

3. Hardness (or) strength of pure material is very poor and the max strength will be at a point of max solid solubility of one material into another because alloys are always stronger than the pure metal.
4. Generally Density is higher for low melting point materials.

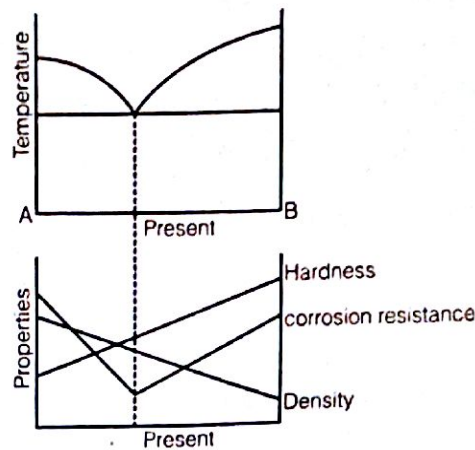


Fig. 2.30 : Properties of alloy for completely insoluble system

2.14 HIGH STRENGTH LOW ALLOY STEEL (HSLA)

The major alloying element in HSLA are copper, vanadium, nickel and molybdenum. In high strength low alloy steels copper is used as an anticorrosive agent. It improves the corrosion resistance 3 times to that of chromium. Vanadium increases hardness and promotes fine grain structure which leads to stronger the material. Nickel strengthens by solid solution and increases the tendency to retain austenite, with higher % of carbon. Molybdenum resists coarse grain formation and increases the hot hardness. HSLA possesses higher strength than plain carbon steels. Its strength can be increased by heat treatment process. These materials are highly machinable, formable and more resistant to corrosion. In HSLA, % of carbon is in the low carbon steel range, so yield point phenomenon appears during deformation. This phenomenon produces stretcher strains in which material gets accumulated in the different regions which leads to fracture. So, before using the material yield point phenomenon should be avoided.

POINTS TO PONDER

1. Iron ore are Magnetite (Fe_3O_4) and real hematite (Fe_2O_3).
2. Blast furnace comprise a throat, stack, body, bosh and hearth.

3. Material	% of carbon	Material	% of carbon
Plain carbon steel	0.05 - 2.0%	White cast iron	1.75 - 2.30%
Low C steel	0 - 0.3%	Malleable cast iron	2.20 - 3.60%
Medium C steel	0.3 - 0.7%	Gray cast iron	2.50 - 3.75%
High C steel	Beyond 0.7%	Pig iron	3.00 - 4.00%
Wrought iron	0.02 - 0.03%		

4. Gray cast iron

- This is obtained by allowing molten metal to cool and solidify slowly.
- It contains greater part of carbon in graphite flake form.

- It is brittle and its strength is greater in compression than in tension.
- Used for making parts of intricate shape.
- Free graphite structure seems to acts as lubricants.

5. White cast iron

- Contains carbon exclusively in form of cementite.
- Obtained when allowed to cool rapidly.
- Is very hard, brittle and fractured surface has silvery metallic appearance.
- It is widely used for producing of wrought iron.
- It does not rust as gray cast iron.

6. Malleable cast iron

- Having carbon in the form of combined form.
- It is hard and brittle
- Malleable castings do passes a degree of toughness.
- Mainly used for thin walled small workpieces.

7. Ductile iron *Nodular*

- Spheroidal graphite iron, also called nodular cast iron.
- Graphite is in the form of spheroids not in form of flakes.
- High fluidity and ductility.
- Used in hydraulic cylinders, valves pipe fitting cylinder head for compressors and diesel engines, etc.

8. MeChanite cast iron

- Cast iron treated with calcium silicide which acts as a graphatiser and produces a fine graphite structure giving cast iron of excellent mechanical properties.
- It has high strength toughness, ductility and easy machinability.

9. Wrought iron

- It has iron as much as 99%.
- Noncorrosive slag constituent causes wrought.
- It cannot be melted while heating it becomes soft enough to take any shape.
- It can withstand sudden and excessive shock loads.
- It can neither be hardened nor termpered like steels.

10. Iron	% of carbon
Black Iron	2.2 - 2.8%
White Iron	3.2 - 3.6%

11. Iron Type	hardness	Application
Malleable cast iron	120	Valve bodies, hinges, machine castings etc.
Gray caſt iron	130	Ingots, moulds, pistons, machine castings, automobile cylinders etc.
Nodular cast iron	180	Parts subjected to bending and vibration and where strength and ductility are important.
White	400	Rolls, dies wearing plates, stamping shoes, etc.

12. Effects of elements on cast iron

Element	% age	Effect
Carbon	~ 6.67%	Graphite (Cooled slowly) tough iron, easy to machine cementite (rapidly cool) high tensile strength, difficulty to machine element.
Silicon	2.5%	Promotes the formation of free graphite which makes the iron soft and machinable.
Sulphur	0.1%	Makes hard and brittle.
Manganese	0.75%	Harden the cast iron by encouraging the formation of carbide.
Phosphorus	1.0%	Aids fusibility and fluidity but induces brittleness.
Nickel	0.25 - 2.0%	Acts as a graphitiser, to resist corrosion and low expansivity
Chromium	0.15 - 0.9%	Acts as a carbide stabilizer, increases strength, hardness and wear-resistant.
Molybdenum	0.25 - 1.5%	To improve tensile strength, hardness to casting and also improves toughness, fatigue strength machinability, hardenability.
Copper	0.02 - 2.5%	Promotes formation of graphites.
Vanadium	0.01 - 0.5%	Increases hardness strength and machinability.

13. Furnace Type Tonne of steel produced in 24 hours

Bessemer converter	1200
Open hearth furnace	800
Electric Furnace	30 - 80

14. Killed steels

- Steels containing more than 0.25% carbon are called killed steels and denoted by symbol 'K'.
- Steel is sufficiently deoxidised, no evolution of gas and freedom from blow-holes (i.e. soundness).

15. Semi-Killed steels

- Steel containing carbon ranging from 0.15 - 0.25% are called semi-killed steels.
- It aims to produce metal free from surface blow holes and pipe.
- No symbol is used to represent this type of steel
- Plates and structural products are normally made from this steels.

16. Rimmed Steels

- It aims to produce a clean surface in carbon content.
- Steels are partially deoxidised.
- 'R' stands for rimmed steels

17. Effects of elements on steel

Element	%	Effect
Carbon	0.3%	Increases strength, elasticity, hardness but lowers the ductility and impact strength.

Silicon	0.05 - 0.3%	To prevent steels from porous, acts as a good deoxidiser makes tougher and harder.
Manganese	0.3 - 1.0%	Serves as deoxidising and purifying agent it combines with sulphur to decrease the harmful effect of element on steel.
Sulphur	0.1%	Red-shortness i.e. increases brittleness, increase tensile strength, yield point, fatigue limit and decreases corrosion resistance.
Phosphorus	0.2%	Imparts coldshortness. It increases tensile strength but at same time reduces impact strength and ductility.

18. Free cutting steels

- Subjected to light loads
- high machinability and high quality surface finish because of high sulphur and phosphorous content.
- Sulphur increase the surface finish by reducing the friction.
- Phosphorous reduces the brittleness.

19. Fine grained steels have less tendency to crack during heat treatment but have better toughness.

20. Effect of alloying elements in alloy steels

Alloying Element	Effects
Nickel	Toughness, corrosion resistance and deep hardening
Managanese	Deoxidizes, contribute to strength and hardness
Chromium	Toughness, corrosion resistance and hardenability
Silicon	Deoxidizer increases susceptibility of steel to decarburization and graphitization
Molybdenum	Hardenability, increases tensile and creep strength
Vanadium	Deoxidizes and promotes fine grained structure
Copper	Increases resistance to corrosion and strengthening agent
Aluminium	Deoxidizer
Boron	Increases hardenability

21. Different applications of steels

Steels	Application
Dead Mild	Chains, rivets, seam welded pipe, tin plates
Mild steel	Screws, gears, shafts, drop forgings, free cutting steels
Medium carbon	Connecting rods, axles, shafts, crank shafts, die block etc.
High carbon	loco-tyres, rails, wire ropes, drop-hammer dies, cold chisels, punches, hammers etc.

23. Special alloy steel

Special alloy steel	Application
Magnet steel	Magnetos, loud speakers, electrical machine and instruments 15-40% Co, 0.4-10%W
Heat Resisting steels	Working at high temperature. For furnace parts, annealing boxes Cr, Ni and W, 0.3% C

Shock Resisting steels	In leaf and coil springs and where in fatigue stresses 2.25% W, 1.5% Cr, 0.25% V 0.5 C
Stainless steels	(a) Austenitic stainless steels ❖ high ductility (18/8 stainless steel) ❖ are non magnetic (15-20% Cr, 7-10% Ni) ❖ Titanium and niobium added to stabilise the carbon (b) Martensitic stainless steels ❖ These steels are hardenable by heat treatment 10-14%Cr (c) Ferritic stainless steel ❖ These can not be hardened by heat treatment ❖ Stainless steels have high strength and toughness as well as good resistance to corrosion ❖ These are used in all type of surgical and dental instruments house hold appliances utensils etc. ❖ When carbon contents is as low as 0.09% the product is called stainless iron.
Marging steels	Iron based 18 Ni 8 Co High fracture toughness 5 Mo + small amount of Al and Ti + 0.03% C.
High Speed steels	(a) 18-4-1 HSS 18% W, 4% Cr 1%V (b) Cobalt HSS 20% W, 4% Cr, 2% V Cobalt is added to increase hot hardness and wear 12% Co resistance (c) Vanadium HSS 0.7 C + more than 1% V excellent abrasive resistant (d) Molybdenum HSS 6% Mo, 6% W, 4% Cr, 2% V excellent toughness and cutting ability.
24. Alloying element	Effect on HSS
Chromium	Reduces scaling
Vanadium	Abrasion resistance
Tungston	Hot hardness
Molybdenum	Hardenability
Cobalt	Hot hardness and wear resistant

2.15 DEFECTS IN THE MATERIALS

2.15.1 Points defects

- 1. Vacancy Defect :** It appears due to the missing of atom from the lattice.



Fig. 2.31 : Vacancy Defect

2. Interstitial defect :

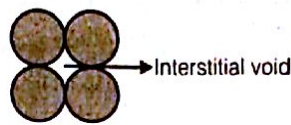


Fig. 2.32 : Interstitial void

When the foreign atom occupies the interstitial site that defect is called interstitial.

3. **Substitutional defect :** If the regular atom is replaced by another foreign atom this defect is called substitutional defect.



Fig. 2.33 : Substitutional Defect

4. **Frenkel defect :** When the atom in the lattice point goes and occupies the interstitial void of other atom then it is called frenkel defect.

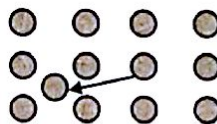


Fig. 2.34 : Frenkel Defect

5. **Schottky defect :** In the combination of cation and anion if there is a vacancy defect it is called schottky defect.

2.15.2 Surface Defects

1. **Grain boundary defect :** The bond length is more at the grain boundary due to orientation mismatch and can easily be broken. So, atmospheric oxygen reacts with the atom at grain boundary and corrodes. So finer the grain structure lower will be the corrosion resistance.

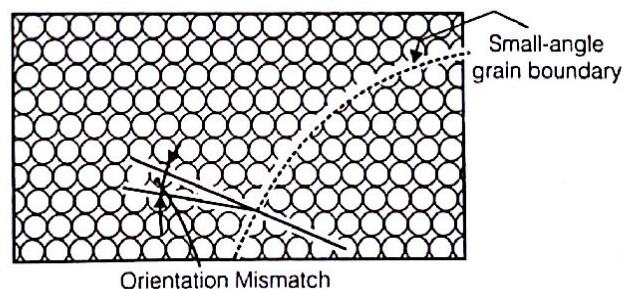


Fig. 2.35 : Grain boundary defect

2. **Tilt boundary defect :** When the orientation mismatch at the grain boundaries is $\frac{1^\circ}{2} - 1^\circ$, grain boundaries are called tilt boundaries.

3. **Twin boundary defect** : When the orientations on one side are mirror image of opposite side, such grain boundary defects are called twin boundary defects.
4. **Stacking faults** : When the grain boundaries on both the sides are parallel to each other with slight disturbance of bonds in a very small region, such grain boundaries are called stacking faults.

2.15.3 Line Defects

1. **Edge dislocation** : Although millions of dislocations are already there in the material but to understand the concept let us assume that there is a perfect material and one face of the material is fixed i.e. restricted to move. On the opposite face a uniform pressure is applied on 50% area. Once this pressure exceeds beyond a certain value, slipping of atoms takes place. This unit amount of plastic deformation which appears in the direction of applied load is called burger vector. There will be a boundary 'AB' as shown in Fig. 2.36 between slipped and unslipped regions called edge dislocation. In this case burger vector is perpendicular to the dislocation line.

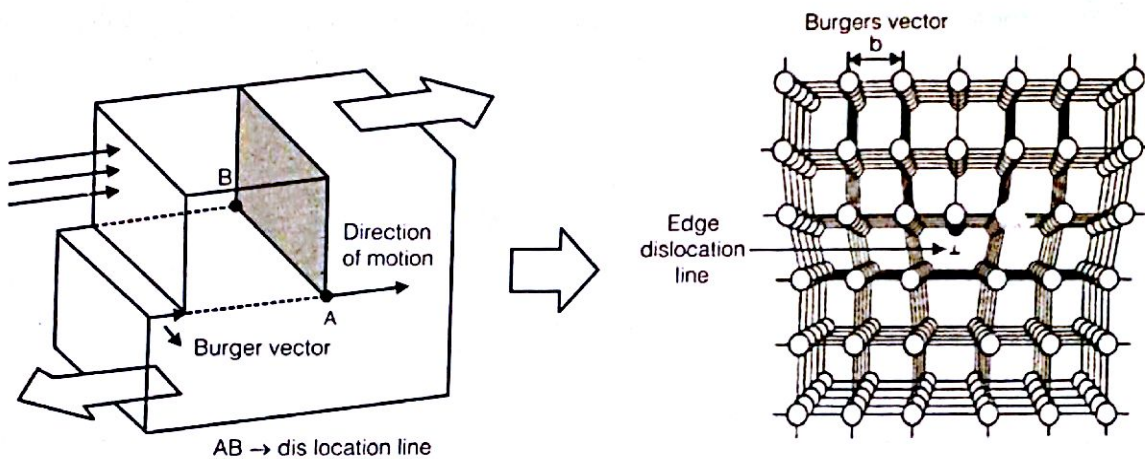


Fig. 2.36 : Edge dislocation

- (a) There appears an extra half plane at the dislocation line.
- (b) The interstitial void at the dislocation line is larger in size.

Upon applying load on any material, dislocations move in the direction of applied load. If the dislocations come out of the surface it is said that plastic deformation has begun in the material. The representation of dislocation motion is phase in Fig. 2.37. If extra half plane is above the dislocation line it is called positive edge dislocations represented by $\perp$ and if half plane is below the dislocation line it is called negative edge dislocation represented by symbol T.

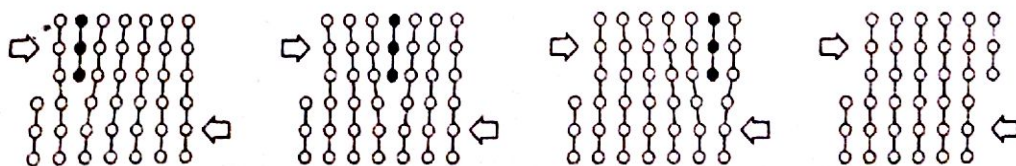


Fig. 2.37 : Dislocation Motion

2. **Screw Dislocation** : formed by a shear stress that is applied to produce the distortion shown in figure 2.38. The screw dislocation derive its name from the spiral or helical path or ramp that is traced around the dislocation line by the atomic planes of atoms. The burger vector in this case is parallel to the dislocation line.

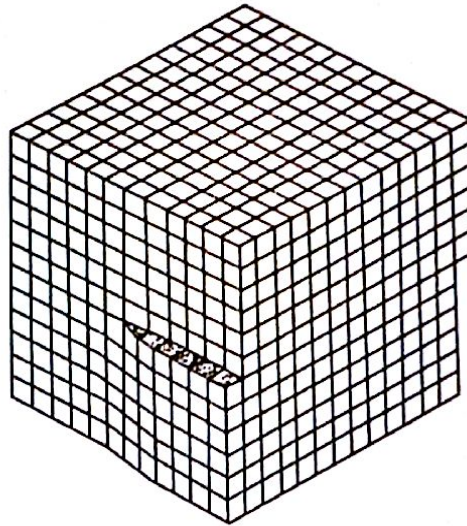


Fig. 2.38 : Screw Dislocation

2.16 YIELD POINT PHENOMENON

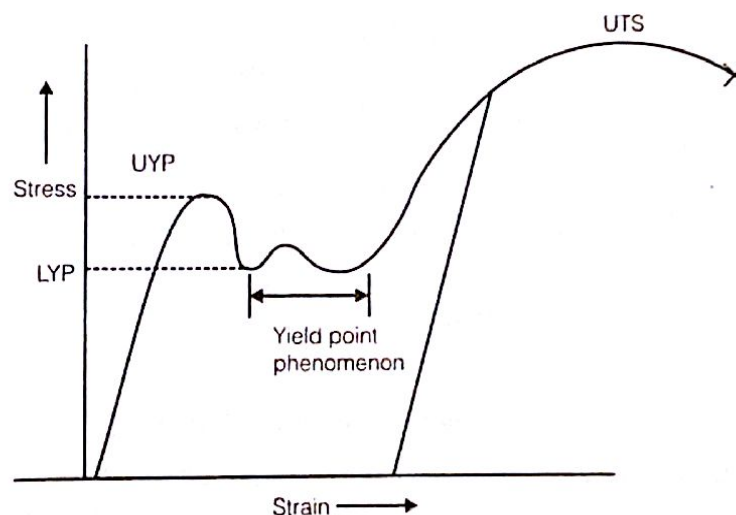


Fig. 2.39 : Yield point phenomenon

Carbon in iron is an interstitial impurity but the interstitial space is much smaller than the size of carbon atoms. So, by the process of diffusion, carbon get accumulated at the dislocation site, it is called cottrell atmosphere. This produces lattice strains. So, extra stresses are required to break this cottrell atmosphere and jump the dislocation to the new site. That is why upper yield point appears. Once the dislocation jumps to the new position, since there is no cottrell atmosphere,

lesser stresses are required to keep the dislocation moving so lower yield point and yield point phenomenon appears in the low carbon steel material. Upon unloading the specimen from the work hardening region (as shown in Fig. 2.39) and reloaded again, the yield point phenomenon will not appear because of absence of C at the dislocation site. But after a certain period of time when the sample is reloaded the yield point phenomenon will reappear because C or N will again diffuse at the dislocation site. This time period is called strain aging time. This phenomenon does not appear in medium and high C steels because C is not only present at dislocation site but also in the other interstitial sites. So when the dislocation jumps to the new position C is ready to diffuse. So lower yield point does not appear.

2.17 STRENGTHENING MECHANISM

2.17.1 Alloying

If the foreign element occupies the interstitial site it produces compressive strain field in the host atoms. It is because interstitial void is always smaller than the size of impurity atom. If the impurity atom occupies the substitutional site and if its size is smaller, it produces tensile strain field. If the impurity size is bigger than the host atoms it produces compressive strain field. These strain fields create an obstacle in the movement of dislocation. This increases the strength of material. So, alloys are always stronger than the pure metal. Both carbon and nitrogen occupies the interstitial site in iron but nitrogen produces harder and stronger materials because it produces strain field of larger intensity.

2.17.2 Grain refinement

When the grain boundaries are less than that of atoms are called coarse atoms and when they are more they are called fine atoms. As we know the region of orientation mismatch are called grain boundary when the dislocation starts moving at the grain boundary it changes its directions which requires more amount of stress. So the strength for fine materials will more than that of coarse materials.

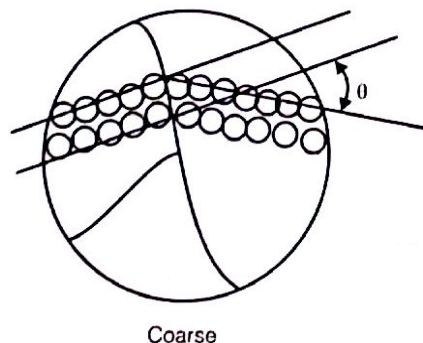


Fig. 2.40 : Orientation mismatch of grains

As soon as the dislocation approaches the grain boundary it has to change its orientation because atoms are arranged in a different direction this requires extra stress. So, grain boundaries creates an obstacle in the movement of dislocation. So, finer the grain better will be the strength of material.

2.17.3 Work (strain) Hardening

Upon cold working (temperature less than 0.4 temperature where temperature is melting point in K) the number of dislocations in the material increases. How much dislocation multiplication takes place, is the property of material and it is expressed by work hardening exponent (n) in the flow curve equations $\sigma_t = K\epsilon^n$, where k is strength coefficient, σ_t is true stress and ϵ is true strain.

Higher is the value of n , more dislocations will be created upon cold working the material. These dislocations pile up at the grain boundary and create a dislocation forest. Since dislocation-dislocation interactions are repulsive in nature, these dislocation forests create a back stress in the movement of dislocation. This increases the strength of material upon unloading the specimen from the region of work hardening and reloading in opposite direction, back stresses now support the movement of dislocation. As a result of that yield point in opposite direction appears prematurely. This phenomenon is called Bauschinger effect.

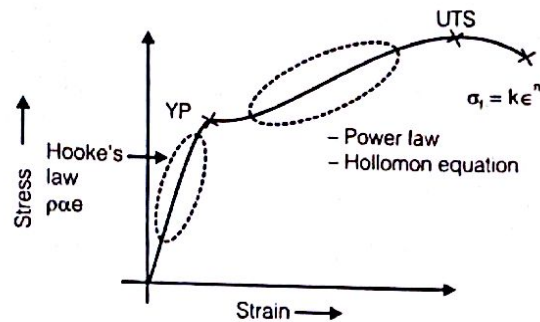


Fig. 2.41

$$\sigma_0 = \frac{P}{A_0}$$

where σ_0 is nominal stress, A_0 is the nominal area and P is the applied load.

$$e = \frac{dl}{l_0}$$

where e is engineering or nominal strain, l_0 is the nominal length and dl is the change in length

$$\sigma_t = \frac{P}{A} = \frac{P}{A_0} \times \frac{A_0}{A}$$

where A is instantaneous area of the specimen.

$$\text{volume} = \text{constant} \rightarrow \text{So } A_0 l_0 = A l$$

So,
$$\frac{A_0}{A} = \frac{l}{l_0}$$

$$\sigma_t = \frac{P}{A_0} \times \left(\frac{l}{l_0} - 1 + 1 \right) = \frac{P}{A_0} \times (e + 1)$$

$$\sigma_t = \sigma_0 (e + 1)$$

$$d\epsilon = \frac{dl}{l_0}$$

where l is instantaneous lengths, upon integrating it

$$\epsilon = \int_{l_0}^l \frac{dl}{l} = \ln \left(\frac{l}{l_0} \right)$$

So

$$\epsilon = \ln (e + 1)$$

Also $\sigma_f = \frac{P}{A}$... (1)

$\Rightarrow P = \sigma_f A$

$$\frac{dP}{d\epsilon} = \frac{d}{d\epsilon}(\sigma_f A) = \frac{d\sigma_f}{d\epsilon} A + \sigma_f \frac{dA}{d\epsilon}$$

... (2)

Volume

$$V = Al$$

Differentiating this equation we get

$$0 = \frac{dA}{d\epsilon} l + A \frac{dl}{d\epsilon}$$

... (3)

Also we know that

$$d\epsilon = \frac{dl}{l}$$

putting in equation (3)

So $\frac{dA}{d\epsilon} = -\frac{A}{l} \frac{dl}{d\epsilon} = -A$

From equation (2)

$$\frac{dP}{d\epsilon} = A \frac{d\sigma_f}{d\epsilon} - \sigma_f A$$

at UTS

$$\frac{dP}{d\epsilon} = 0$$

So,

$$\sigma_f = \frac{d\sigma_f}{d\epsilon}$$

... (4)

This is true only at UTS point

From Hollomon equation

$$\sigma_f = K\epsilon^n$$

$$\frac{d\sigma_f}{d\epsilon} = K n \epsilon^{n-1} = K \frac{n \epsilon^n}{\epsilon} = \frac{n}{\epsilon} \sigma_f$$

... (5)

Comparing equation (5) and (4) we can see that at UTS $[n = \epsilon]$.

Example : 2.8

The ultimate tensile strength of a material is 400 MPa and elongation up to maximum load is 35%. If the material obeys power law then what is the true stress-strain relationship.

Solution :

Nominal UTS

$$\sigma_0 = 400 \text{ MPa}$$

$$e = 0.35$$

So

$$\epsilon = \ln(1 + e) = \ln(1.35) = 0.3$$

$$\sigma_f = \sigma_0 (1 + e) = 400(1.35) = 540 \text{ MPa}$$

at UTS

$$n = \epsilon = 0.3$$

$$\sigma_f = K \epsilon^n$$

$$540 = K (0.3)^{0.3}$$

$$K = 775$$

So power law equation is

$$\sigma_f = 775 \epsilon^{0.3}$$

2.18 TYPE OF BOND

Solid state exhibits a crystal structure which is having a definite geometry except amorphous state like glass. In crystal structures there are four types of bonding.

Ionic Bond : Strong electrostatic attraction between cation and anion is called ionic bond. These bonds are permanent and atom doesn't drift throughout the lattice structure.

Covalent Bond : In this type of bond there is a sharing of one or more electrons from the adjacent atoms.

Metallic bonds : Metallic materials have one, two (or) three valency electrons. These electrons are not bound to any particular atom in the solid and drift through out the entire metal.

Vander Walls Forces : This is the bond arises in neutral atoms like inert gases. When atoms are brought close to each other there is a separation of +ve and -ve charges and a weak attractive force develops.

2.19 TIME TEMPERATURE TRANSFORMATION (TTT) DIAGRAM

S → Starting Point

F → Final state (or) Point

Prof. Bain heated the steel samples having an eutectoid composition at a temperature at which austenite is stable. These samples are subsequently quenched to different temperatures below 725°C. The first sample was quenched to 700°C and it was observed that for a substantial period of time there was no change in the micro structure of 'Austenite'. Although austenite cannot be stable below 725°C. This period is called incubation period. Upon decreasing the quenching temperature incubation period decreases and at 550°C it is only 'one sec'. Upon decreasing the quenching temperature further, again there is increase in the incubation period.

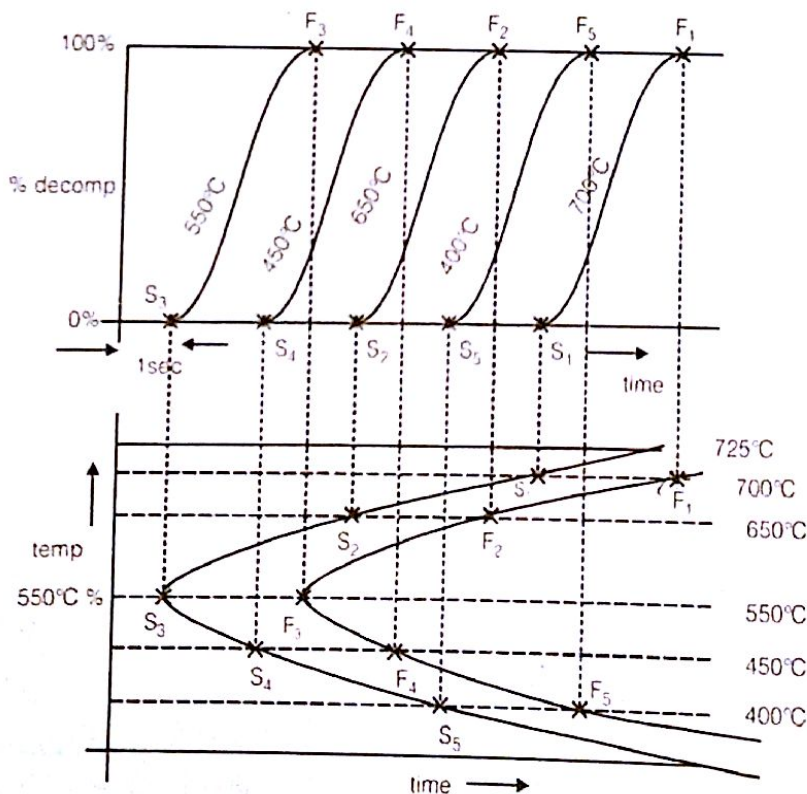


Fig. 2.42 : Construction of TTT diagram

Upon projecting the % decomposition V_s time graph, to temperature vs time graphs 2 'C' curves appears this diagram is called **Time-Temperature-Transformation curve (or) TTT Curve or C-Curve or S-curve or Bains Curve**.

The factors responsible for curve are :

1. Driving Force : $\Delta G = G_{\text{final}} - G_{\text{initial}}$

If ΔG is +ve, it means the final phase is stable. If its value is zero it means the phase is neutral and it is -ve it means the final phase is unstable. As there is a decrease in temperature the (ΔG) driving force value increases and so incubation period decrease from 725°C to 550°C.

2. Atomic Mobility (Diffusion) : It decreases with decrease in temperatures slightly below 725°C, the driving force is very low that is why incubation period is more. Below 550°C although the value of driving force is very high but due to lower temperature, diffusion is very low. This increases the incubation period.

In the TTT-diagram there appears two lines other than C-curves at 220°C and 100°C horizontal to time axis.

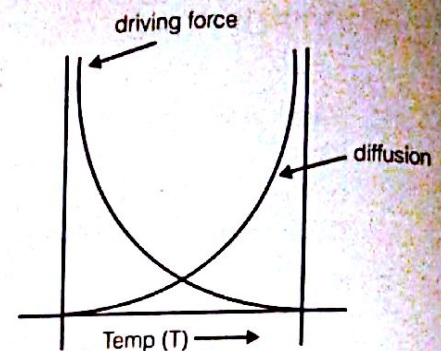


Fig. 2.43 : Driving force and diffusion variation with temperature

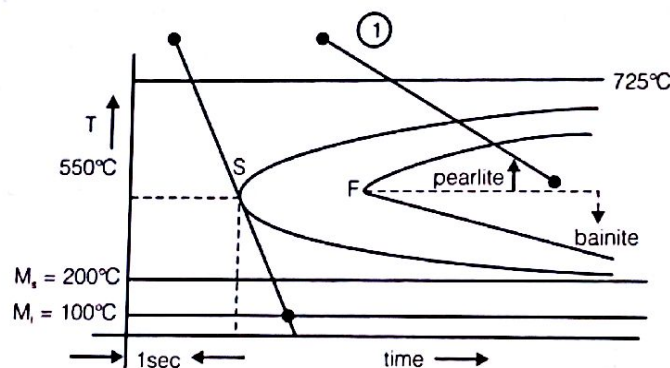


Fig. 2.44 : Critical Cooling Rate

220°C- M_s → Start of martensite

100°C- M_f → Finish of martensite

If the cooling rate is such that, it just touches the nose of TTT diagram is called critical cooling rate (CCR). Any cooling rate greater than (or) equal to CCR will not produce pearlite and in the microstructure carbon will freeze at its location and it is like colloidal solution of carbon (or) cementite in ferrite. This phase of iron is called 'martensite', which is the hardest phase of iron. All the lines on TTT diagram are that of decomposition of austenite into some other micro structure. Once the austenite converts into some other microstructure it never reconverts again. The slow cooling process produce coarse structure and fast cooling process produce fine structure. It can be observed that bainite cannot be produced by continuous cooling. To produce bainite, the sample has to be quenched below the nose of TTT diagram but above martensite start line (220°C). The sample is then maintained at this temperature for substantial period of time till entire austenite converts into bainite. The process is called **Austempering**.

The advantages of austempering are :

1. Brittle martensite does not form.
2. Quenching cracks between core and surface do not develop.
3. Ductility is increased.
4. Impact strength and toughness are increased.

Only small sections are suitable for austempering because big sections can not be cooled rapidly to avoid formation of pearlite. Steel sections less than 12 mm thick are suitable for austempering.

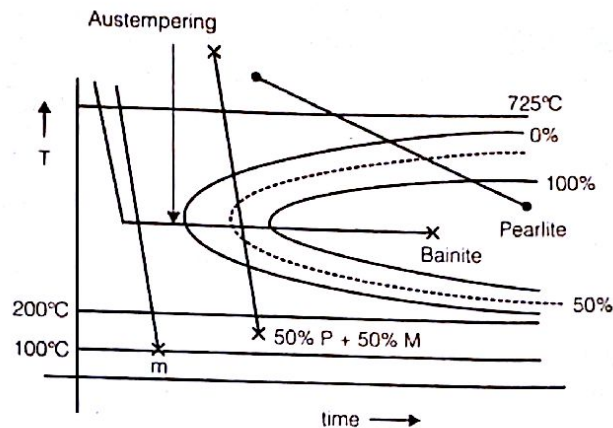


Fig. 2.45 : Different cooling rate results to different microstructure

Upon quenching austenite specimen into water since surface is coming in contact with the quenched medium. It will immediately convert into martensite but the core is still austenite. After some time when core converts into martensite its volume will expand because martensite is having lower density. This produces crack over the surface. Cracks in quenching are due to density difference and not due to thermal stresses. These quenching cracks can be avoided by :

(1) Martempering or Stepped quenching :

- (a) The austenite sample is initially quenched into a hot bath maintained below the nose but above M_s line.

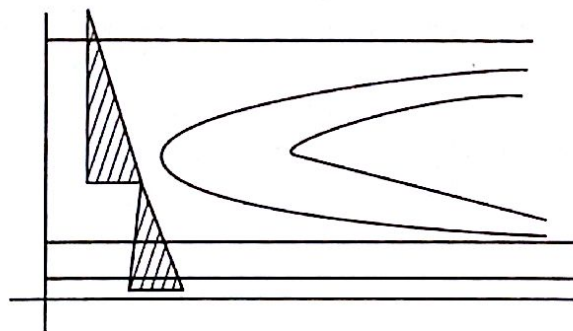


Fig. 2.46

- (b) Quenching in two medium or Martempering : Articles are first quenched in water to a temperature of 300-400°C and then quickly transferred to a less intensive medium like oil or air where they are held until they are completely cooled. The purpose of transfer to the second medium is to reduce internal stresses associated with the austenite to martensite transformation. This method is widely used in heat treatment of C-steel tools like taps,

disc, milling cutters etc. A larger holding time will cause austenite decomposition. Austenite is transformed into martensite during the subsequent period of cooling to the room temperature. This treatment gives a structure of martensite and retained austenite. Martempering has the following advantages over conventional quenching.

- (i) Less volume changes occurs due to the presence of a large amount of retained austenite and the possibility of self tempering of the austenite.
- (ii) Less distortion since the transformation occurs almost simultaneously in the entire volume.
- (iii) Less danger of quenching cracks. Martempering can be applied for thin sections from 5 to 8 mm thickness.

2. Hardening with self tempering : Here the article is not held in the quenching medium until it is completely cooled but is withdrawn to retain a certain amount of heating the core which accounts for the self tempering. This method is applied for chisels, sludge hammers, hand hammers, centre punches and other tools which require a high surface hardness and tough core.

3. Alloying

Hardenability is the ease of martensite formation i.e. The ability due to which austenite sample can be transformed into martensite without any cracks. This is possible by shifting the entire TTT diagram towards right. Upon adding the impurity material if it occupies the substitutional site it will produce either tensile or compressive strain field. These strain field creates an obstacle in the diffusion process of Carbon atoms. So, for the equilibrium to be happen not only carbon has to jump from one interstitial site to another but also the substitutional impurity has to jump to some vacancy site. This process takes time and as a result of that entire TTT-diagram shifts towards right. Hence martensite can be produced by air quenching.

2.20 HEAT TREATMENT

Heat treatment is an important operation in the manufacturing process of many machine parts and tools which imparts high mechanical properties to steels. Heat treatment can be classified into 5 main groups. The first group comprises first order annealing which is employed to relieve internal stresses reduce the hardness and to increase the ductility of the strain hardened metal, it is also known as stress relieving.

The second group or full annealing which involved phase recrystallization consists in heating alloys above the temperatures require for phase transformation. This is followed by slow cooling. Full annealing substantially changes the physical and mechanical properties and may refine grain structure.

In the third group hardening alloys are heated above the phase transformation temperature and then rapidly cooled to room temperature. Thus hardening causes the formation of unstable structures.

The fourth group tempering involves the reheating of hardened steels to a temperature below that required for phase transformation so as to bring it nearer to equilibrium state.

The fifth group chemical heat treatment involves the saturation of the surface of steel with a certain element by the diffusion of this element, from the surrounding medium at a high temperature it is also called case hardening.

2.20.1 Annealing

Annealing is the heating of steel to austenite temperature and then cooling slowly in the furnace. The purpose of annealing is

1. To reduce hardness
2. To improve machinability
3. To increase or to restore ductility
4. To relieve internal stresses
5. To reduce or eliminate structural inhomogeneity
6. To refine grain size
7. To prepare steel for subsequent heat treatment

Slow cooling results in the formation of spheroidal carbide and (coarse) lamellar pearlite. These products are very soft. The cooling rate during annealing varies from depending upon the alloying element in the steel and lower rate of cooling is used for alloy steels as compared to plain C-steels. Annealing results in the formation of ferrite, spheroidal cementite and coarse pearlite. All these phases and micro-constituents are relatively soft and therefore this is known as softening treatment and produces relatively lower hardness values while ductility increases. There are 4 types of annealing process.

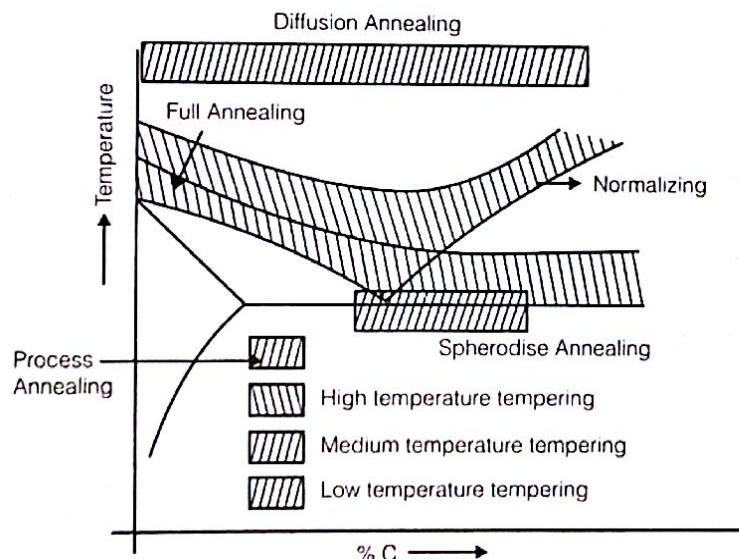


Fig. 2.47 : Regions of temperature for different heat treatment processes

1. **Full Annealing** : Primary objective of this process is to reduce hardness and increase ductility. The process involves.
 - (a) Heating the steel to about 50 to 75°C above the upper critical temperature for hypoeutectoid steels and above the lower critical temperature for hyper eutectoid steel.
 - (b) Holding it at this temperature for a sufficient time depending upon the thickness of object the holding time is 3-4 min/mm of thickness of the largest sections.
 - (c) Slowly cooling in the furnace. The rate of cooling varies from 30°C-200°C per hour depending upon the composition and stability of austenite, when slow cooling is done austenite is decompose into coarse pearlite and ferrite structures in hypoeutectoid steels and in eutectoid steels is converted into pearlite. Hyper-eutectoid steels may undergo full annealing & cooling and austenite decomposes into pearlite and cementite.

2. **Process Annealing** : It is usually carried out to remove the effects of cold working and to soften it to make it suitable for further plastic deformation as in the case of sheet and wire industries. It is the re-crystallization of cold worked steel by heating below the lower critical temperature. The exact temperature depends upon the extent of cold working grain size composition and holding time. During re-crystallization the deformed grains are reoriented to increase plasticity and remove internal stresses. It should be noted that this process produces no change in microstructure and the process is primarily used for low carbon steels.
3. **Spheroidise Annealing** : This process is applied to high carbon steels which are difficult to machine. It causes the formation of all carbides in the steel in the form of very small globules or spheroids like spheres. The process consists of heating the steel near the lower critical temperature (730-770°C), holding at this temperature and then cooling slowly to 600°C. The rate of cooling in the furnace is 25-30°C/hr. Varieties of heat treatment can be used to produce a spheroidized structure but all of them are relatively lengthy and costly.
4. **Diffusion Annealing** : Diffusion annealing or homogenizing is applied to alloy steel ingots and heavy complex castings for eliminating the chemical inhomogeneity within the separate crystals by diffusion. Homogenizing is carried out at temperature 1000-1200°C. The optimum temperature being 1150°C at which diffusion proceeds quite easily. The steel is heated to 1150°C as the highest rate available for the furnace. Holding time is kept at minimum, followed by cooling with the furnace for 6-8 hours to 800-850°C and then further cooling in air. After Homogenizing castings undergo full annealing to refine their structures. Higher temperatures are selected to enable diffusion more and more.

2.20.2 Normalizing

It is a final heat treatment process which is given to a product, which are subjected to relatively high stresses, the process consist of heating steel to a temperature 40-50°C above the line where austenite is stable, holding at that temperature for a short period and subsequently cooling in air at room temperature. **This is known as air quenching**, Normalizing produces micro-structures consisting of ferrite and pearlite for hypo-eutectic steel and pearlite and cementite for hypereutectoid steels. This alloy steel structure consist of ferrite and sorbite (medium pearlite). Normalizing raises the yield point, ultimate tensile strength and impact strength in steels. Normalized steels are harder and stronger but less ductile than annealed steels with the same composition.

Comparison between Normalizing and Annealing :

1. Normalizing requires a heating range which is about 40°C above that of annealing.
2. Mechanical properties of steels are better than those produced by annealing.
3. Heat treatment process is of short duration due to increased rate of cooling of the metal in air.
4. If mechanical properties is not the main aim of the heat treatment, better machinability and removal of internal stresses is possible in annealing than obtained by normalizing.

2.20.3 Hardening

Hardening is a process in which steel is heated to austenite temperature held at this temperature and then quenched in water oil or molten salt baths. Hypoeutectoid steels are heated from 30-50°C above the Upper Critical Temperature (UCT), while hypereutectoid steels are heated above the lower critical temperature.

Cooling at a rate higher then the critical value enables the austenite to be supercooled to martensite point. Due to rapid cooling carbon freezes at its location and the microstructure appears like collidal solution of cementite in ferrite. This microstructure is called martensite which is very hard and brittle. Hardened steel is very brittle and can not be used for practical purposes. After hardening

steel must be tempered to reduce brittleness, relieve the internal stresses caused by hardening and to obtain the desired mechanical properties. Hardening followed by tempering improves the mechanical properties of steels. In case of tool steels, it increases the hardness and wear retaining the toughness at the same time. In case of structural steel, it improves strength, ductility and toughness.

The process is carried out in three stages :

1. Heating the object to a temperature above the critical point.
2. Holding the object at this temperature for a definite period.
3. Quenching in a suitable medium.

The hardening process is based on the metallurgical reaction of eutectoid. This reaction is dependent upon.

- (a) Adequate C-content to produce hardening.
- (b) Austenite decomposition
- (c) Heating rate and time.
- (d) Quenching medium.
- (e) Quenching rate.
- (f) Size of the part.
- (g) Surface condition.

(a) Adequate C-content : In order to produce hard structures like martensite, atleast 0.5% C must be present. Carbon increases the hardness and upto 1% wear resistance surface is obtained. These are some alloys which remain dissolved in the austenite and become very hard during decomposition of austenite to martensite.

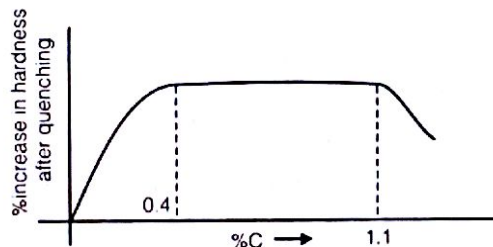


Fig. 2.48 : Hardness Vs Percentage C

It can be seen from the figure that only medium carbon steels can be heat treated. The reason is that only eutectoid composition leads to martensite formation. Pro-eutectoid phase does not contribute to the formation of martensite.

- (b) Austenite Decomposition :** The TTT diagram relates the decomposition of austenite with respect to time and temperature conditions. This diagram explains the decomposition of austenite to various structural components like pearlite, bainite and martensite.
- (c) Heating rate and heating time :** The heating rate and time depends on the composition of steel, its structure, residual stresses, form and size of the part to be hardened. If the heating rate is too high there will be a temperature gradient between the surface and the core, the best way is to first heat to the required temperature and hold it at that temperature. The heating time for carbon tool steels and medium alloy structural steel is 25-50% more than for C-structural steels. For high alloy structural steels and tool steels it should be 50-100% higher. Heating in salt baths may be conducted more uniformly and rapidly than heating in box furnaces.

- (d) **Quenching Medium :** The quenching must provide for a cooling rate above the critical value to prevent austenite decomposition into pearlite and intermediate regions. On the martensitic transformation temperature range, cooling should be slower to avoid high internal stresses, distortion and cracking the most widely employed quenching media are water aqueous solutions, oil, air and molten salt.

Water and aqueous solution are most widely used as quenching media in hardening carbon and certain low alloy steels which have a high cooling rate (critical). Some features of water quenching are:

- (i) It tends to form a vapour blanket which reduces the cooling rate.
- (ii) It gives sharp reduction of cooling capacity at higher temps.
- (iii) It gives a high cooling rate in the temperature range of martensite formation which leads to high structural stresses causing deformation, distortion and even quenching cracks.

An addition of NaCl, alkalies, soda and H_2SO_4 to water substantially increases its cooling capacity and provides more uniform cooling. The maximum cooling rate is obtained when 10-15% salt is added. These solutions provide fastest cooling rate.

Mineral oils are suitable for quenching alloy steels in which austenite is highly stable and the critical cooling rate is therefore low. As compared to quenching liquid, oil has the following advantages:

- (i) The cooling rate in the martensitic range is comparatively low. This prevents quenching defects.
- (ii) The quenching capacity of oil is subject to relatively small change in the temperature range which reduces quenching stress.
- (iii) It provides uniform cooling to the sample and there baths are used in case of alloy steels.

Disadvantage includes the comparatively low cooling rate in the range of pearlite and intermediate transformations, high inflammability of oil and its tendency to thicken in the course of time which reduces its quenching capacity.

A water and air mixture apply at a pressure of 3 atm is sometimes use for quenching in hardening heavy articles. Various cooling rates can be obtained by changing the amount of water in the mixture.

- (e) **Quenching rate ($200^\circ C/min$) :** It depends upon the quenching medium. The higher the quenching rate the more is the temperature gradient between the core and the surface.
- (f) **Size and Rate :** Long articles of cylindrical and other cross-section should be quenched with their main axis perpendicular to the both surface. Thin and flat article, should be immersed an edge. The direction of movement during cooling should coincide with the direction of immersion. Heavy articles should be held stationary and the liquid should be agitated.
- (g) **Surface Condition :** When a part of a surface is quenched in water only its surface is in contact and the heat is dissipated from the part to the water through surface only. Cooling rate depends upon the surface area of the part.

2.20.4 Tempering

The martensite which is formed during quenching is too brittle and hence cannot be used in many cases, the residual stresses are also developed during martensite formation hence hardening

should be followed by tempering. Tempering consist of heating the hardened steel to a temperature below the lower critical temperature holding it for sometime and then cooling slowly. It is the final operation in heat treatment.

Some advantages of tempering are :

1. Residual stresses are relived.
2. Ductility is improved.
3. Toughness is increased.

The higher is the tempering temperature, the more will be the residual stresses in which hardness is reduced and toughness is increased at high tempering temperature. The work is cooled slowly after tempering. The cooling rate considerably affect the residual stresses. The slower the cooling the lesser will be the stresses. Rapid cooling in water develops new thermal stresses.

Tempering is classified according to the tempering temperature, because it has much effect on properties of steel.

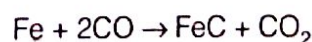
1. **High Temperature Tempering (Sorbite) :** It is employed at 500-650°C. The resulting structure consist of sorbite which gives good strength and toughness. Residual stresses are completely relieved if holding temperature is 100-120°C the holding time can be increased to give desired properties to steel.
2. **Medium Temperature Tempering (Troosite) :** This type of tempering is employed at 350-500°C the resulting steel structure consist of tempered troostite. **This process increases the endurance limit and elastic limit.** After tempering the work is cooled in water. This increases the endurance limit in case of springs. This process is used for spring steel and die steels.
3. **Low Temperature Tempering :** The temperature used in this process is 250°C and the holding time is 1-3 hrs. This process reduces internal stresses increases strength and toughness and provides high wear resistance. This method is employed in manufacture of measuring tools and cutting tools. This is also employed to the components which are surface hardened by carburizing nitriding or carbo-nitriding.

2.20.5 Case Hardening

Hard surfaces are produced on relatively soft cores by case hardening. The parts which are subjected to wear and impact are hardened by surface treatment, the hard surface has good wear resistance and the soft core has good toughness. Since mild steels can not be hardened by quenching, so there strength is increased by case hardening. A hard wear resistance surface is called the case and relatively soft and tough inside is called the core. Following are case hardening techniques :

2.20.5.1 Carburizing

It is applied to low Carbon steel up to 0.18% carbon. In carburizing the Carbon content of the surface layer is increased, the purpose is to obtain a hard layer on the work piece surface after heat treatments. The surface layer is enriched with carbon upto 1%. Carburizing is followed by hardening and low temperature tempering. Low C-steel is heated upto 870°C in the atmosphere which contain carbon.

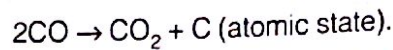


Fe_3C is austenite with dissolve carbon At 870°C the maximum amount of carbon can be dissolve in austenite, carburizing is performed in the following ways.

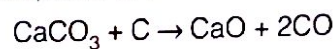
1. **Pack Carburizing :** The parts are surrounded by carburizing mixture and packed in a steel box which is tightly covered and sealed with clay on all sides to prevent entry or exit of

gases. The container is heated to proper temperature for the required amount of time. The temperature is generally 950-1000°C and time is 6-8 hrs. Higher temperatures are selected to enable diffusion more and more. The carbon diffuses into low C-steel during this time the carburising mixture consist of **50% good Charcoal 20% BaCO₃, 5% CaCO₃ and 5-12% Na₂CO₃.**

Barium carbonate acts as energizer it increases the action of carbon on low C-steel. The carburizing mixture is in the form of coarse particles so that sufficient air is trapped, inside the container to form Co.



This atomic state carbon diffuses into austenite. The addition of carbonates activates the carburizer to form the atmosphere of CO.

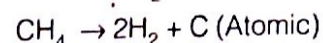
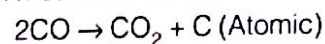


When heating period is over, the boxes are cooled down to 450-500°C and then opened. The carburized parts are taken out and quenched if required. This method is a batch production method.

Disadvantages :

- (a) High labour cost for packing and unpacking.
- (b) It is difficult to quench directly from carburising temperature.
- (c) Much time is needed in heating and cooling.

2. **Gas Carburising :** The work is treated in a medium of gases containing CO and hydrocarbon gases such as CH₄, propane, butane etc. natural gas is also used which gives very high quality of carburized case these gases are mixed with definite amount of air which provides O₂ and forms CO from hydrocarbon gases. Work pieces are heated in an atmosphere of regulating carburizing gases. The temperature, maintained is generally 930-950°C and the holding time is 3-12 hrs depending upon the thickness of the case the chief reaction of carburising is the dissociation of methane and CO



This atomic stage of C diffuses into austenite this process may be performed in continuous furnaces. The work pieces are placed in the furnace such that the gases will have easy access to the surface to be carburized. The work pieces are then cooled down to room temperature and further heat treatment can be done afterwards. This process has many advantages over pack carburizing and hence it is extensively used. The process can be made fully automatic.

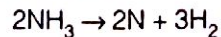
Advantages :

- (a) High quality carburized case can be produced.
- (b) Heat consumed is less.
- (c) Time consumed is also less.
- (d) Process is clean.
- (e) Production cost is low.
- (f) Closer quality limits can be achieved.
- (g) There is more flexibility of operation.

- 3. Liquid Carburising :** In this process molten state bath containing 20% NaCN is used. Cyanide provides C and N. The temperature is maintained at 950°C. The process consist of heating the work pieces in molten bath at 950°C. At this high temperature C and small amount of N are diffused in the surface of work pieces and the case is hardened. The only disadvantages is that the cost of carburizing salt is very high.

2.20.5.2 Nitriding

In nitriding the N content of the surface is increased, this is done by heating the steel in the atmosphere of NH_3 gas the parts to be nitrided are placed in an air tight container. NH_3 is passed continuous through the work pieces at a temperature of 500 to 650°C, NH_3 gas dissociates as follows



This atomic state of nitrogen diffuses into steel surfaces and react with alloys of steel making a case containing the alloy nitrides. Thus the presence of alloying elements such as Al, Cr, Mo etc. is necessary, in order to obtain a case of maximum hardness medium C-steel containing 3% of alloying elements produces hardest case on the steel surface.

The most common size of nitriding case is 0.3 to 5 mm thick, it requires 30-40 hrs at 500-520°C. The time can be reduced by using a double state process in which the work is first heated at 500-520°C and then at 550-600°C for the nitriding process. **After nitriding the work is cooled in the furnace in the spring of ammonia.**

Advantages :

- (a) It increases the hardness of surface layer which is harder as compared to carburising.
- (b) It increases wear resistance, endurance limit and resistance to corrosion.
- (c) No heat treatment is required after nitriding.

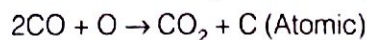
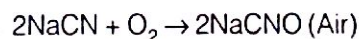
Uses : Nitriding is used during manufacture of gears components of M/c tools, cylinders of powerful engines, cylinder liners, gauges, cams, valves etc.

Disadvantages :

- (a) The case produced is brittle.
- (b) The process is costly compared to carburising.

2.20.5.3 Cyaniding

In cyaniding a thin case of high hardness and wear resistance is produced on C-alloy steels. Work is immersed in molten salt bath containing NaCN which is heated to 820-860°C. This is usually followed by water quenching. The cyanide bath consists of 20-30% NaCN, 25-50% NaCl and 25-50% Na_2CO_3 . The time required is 30-90 min's depending upon the depth of case which is 0.15-0.5 mm. The following reactions occur.



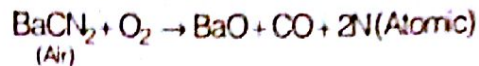
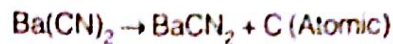
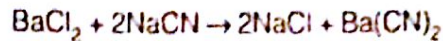
The atomic C diffuses into steel, the work can be directly quenched as soon as it is taken out of bath then low temperature tempering is done at 200°C. The case obtained by cyaniding is of high wear resistant and endurance limit compared to carburising. It should be noted that hardness in case varies in the following sequence

Nitriding > Cyaniding > Carburizing

Cyaniding is used to produce light cases on small parts like small shafts, worms, gears, nuts, springs, pins etc.

2.20.5.4 High temperature or Deep cyaniding

A deeper or thick case of 0.5-2 mm is obtained by heating the work piece in a salt bath at 930-360°C for 1.5-6 hrs depending upon the depth of case required. The bath consist of 82% BaCl₂, 8% NaCN and 10% NaCl. The reaction are :



This atomic C and N diffuse into steel after deep cyaniding the work is cooled in air to refine the grains. The work is again hardened and quenched, this is followed by low temperature tempering at 200°C.

Advantages :

1. It requires less time than carburising.
2. There is less distortion of the work piece
3. Resistance to corrosion and wear is high.

Disadvantages :

1. High cost.
2. Cyaniding bath is toxic hence the worker needs protection.

2.20.5.5 Carbo-nitriding (Gas Cyaniding)

A mixture of ammonia and hydrocarbon gas is used. The work is heated to 850°C in the mixture for 2-10 hrs. This is followed by quenching then tempering is employed at 180°C. Martempering can also be employed instead of low temperature tempering both Carbon and Nitrogen diffuses simultaneously with Carbon diffusing at a higher rate than nitrogen. The alloying elements form carbides and nitrides with Carbon and Nitrogen. The carbides and nitrides lower the stability of austenite and troostite is formed in the case. This reduces the endurance limit, ductility and toughness of the steel.

Advantages : Compared to gas carburising it has the following advantages

1. Carbo-nitriding is performed at lower temperature (850 - 870°C) as compared to Carburizing (930 - 950°C)
2. Higher resistance to corrosion and wear.
3. Operation is clean and there is no soot on workpiece when compared with liquid cyaniding there are following advantages :
 - (a) Medium and large size work can be processed.
 - (b) Nitrogen and Carbon contents in the case can be controlled.
 - (c) Toxic salts are not required.
 - (d) The work can be machined.

The above case hardening techniques meant for low Carbon steels but the following case hardening methods are meant for steels have % in the medium Carbon steel range.

2.20.5.6 Induction Hardening

This process is employed to increase hardness, wear resistance and endurance limit of the surface of the w.p. the heat treatment is given to the surface only by supplying excessive heat to the surface followed by drastic quenching, the surface is heated to the austenite range and then quenched immediately to form martensite. The structure of core remains unchanged because it is

not effected by heat, the components should contain 0.4 - 0.5% carbon or sufficient alloying elements as chromium Ni, or Mo. The work is placed in Helical coils called inductor. The coil consist of several turns of water cooled cu tubing. Alternate current is passed through the inductor and thus alternate magnetic field sets up. The field induces eddy currents on the surface layers and heat is generated. The current density is not uniform through out the cross-section of the w.p. Approximately the 90% of the heat is generated in the work layer of thickness (x) represented by

$$x = 5000 \sqrt{\frac{\rho}{\mu f}}$$

Where f is the frequency, μ is the magnetic permeability and ρ is the electrical resistivity of the metal of the work piece. The heating rate is upto 300°C/sec for hypoeutectoid steels and subsequently the heating time is very small (2 - 50 sec's). The high frequency current is supplied by motor generator and vacuum tube generator. When it is required to increase the strength of the core the work should be normalized before induction hardening. The quenching temperature depends upon the rate of heating if the rate is 500°C/sec it is 1000°C and if it is 250°C/sec it is 900°C. Induction hardening can be performed in three ways :

1. The whole work surface is heated at one time and quenched. This procedure is used for hardening surfaces of small components like shafts and sharp tools.
2. The sections of work are heated and quenched consequently. This procedure is used for hardening generals of Crank shaft teeth of gears and cams of cam shaft.
3. The work in made to travel with respect to stationary inductor or vice versa and spray quenching is done. This procedure is used for hardening long shafts and axles. Generally induction heating is followed by low temperature tempering at about 180°C.

Advantages :

1. Time required is very small hence the process is very quick and productivity is high.
2. Scale is not formed hence machining time is saved moreover material is not lost due to scale formation.
3. The process can be automated.
4. Depth of hardness can be controlled easily.
5. Distortion is reduced.
6. Due to high speed grain growth decarburising do not occur.
7. Both external and internal surfaces can be hardened.
8. It is an efficient mass production method. Almost all components can be uniformly hardened i.e. the quality of all the components is uniform.
9. Where ever required the hardening can be localised and there is no need to protect the remaining surfaces.

Disadvantages :

Each type of work piece requires different fixtures for its holding where as different work pieces can be treated at one time in carburizing and nitriding.

Uses : Induction hardening is mostly used in industry e.g., for hardening the surfaces of cam shaft, crank shaft gears, automobile components, cold rolling mills, splined shaft, crane wheels, spindles, Brake drums etc.

2.20.5.7 Flame Hardening

The process consists of heating the surface of **medium carbon steel by high temperature** gas flame at 2400°C - 3300°C and immediately cooling in air or in water. Heat may be supplied by oxyacetylene torch. The fuel used by the flame may be oxyacetylene, natural gas or kerosene the flame rapidly imparts large amount of heat to the surface. The heat is supplied so quickly to the surface and for so short time, the core remains unaffected.

As soon as the desired temperature is achieved water is immediately sprayed which cools the surface. By proper control of heating and cooling operation the core is not affected by the treatment. The thickness of hardened layer is 2-4 mm and its structure is martensite. The structure of underline layers is troostomartensite.

Advantages :

- There is practically no distortion of the work piece because only small sections of the work piece are heated.
- As heating rate is high the work surface remains clean.
- The process can easily be automated.
- The process is more efficient for large work as compared to induction heating. Its is very economical for large work.

Disadvantages :

- Very thin sections may get distorted extensively.
- Over heating may cause crack.

Uses : It is used to increase wear resistance and surface hardness of piston pins, large gears, hand tools shafts, cams, mill rolls etc.

As it can be seen from the TTT diagram of high carbon steel that martensite finish line appears approximately at 25°C . Hardenability of hypo and hyper eutectoid steels is lower than eutectoid steels. So, upon quenching the material into a bath maintained at room temperature, martansite, pro-eutectoid cementite and retained austenite will be present in the sample.

To convert the sample into 100% martensite, steel sample is quenched into a bath of "liquid N_2 ". This process is called cryogenic treatment of materials.

2.21 TTT DIAGRAMS FOR HYPO AND HYPER-EUTECTOID STEELS

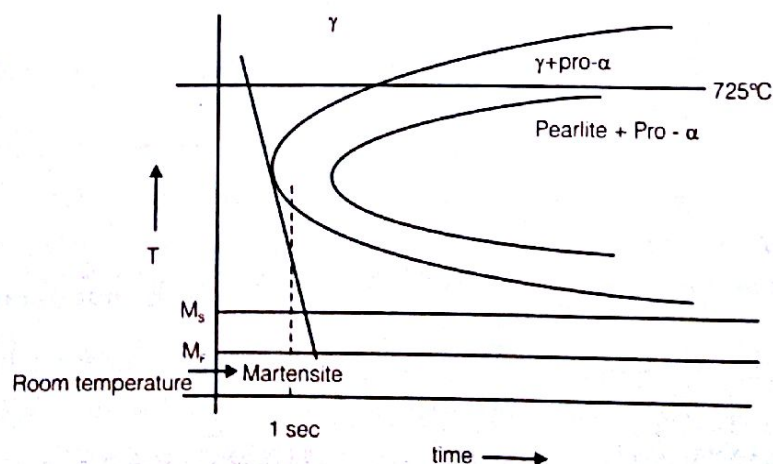


Fig. 2.49 : (TTT diagram of Hypo-eutectoid steel)

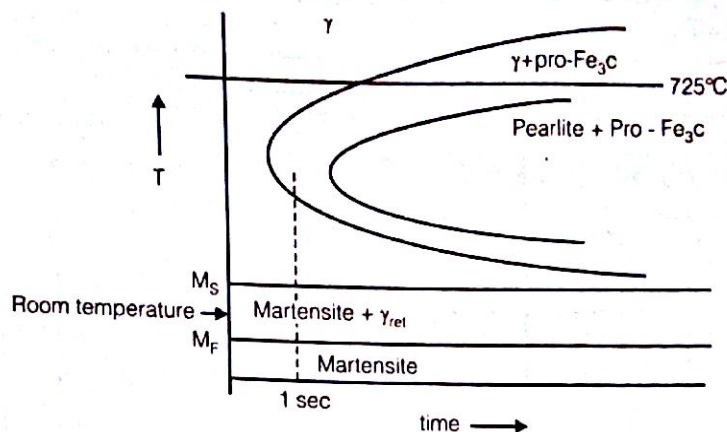


Fig. 2.50 : (TTT Diagram for Hyper-eutectoid steel)

As it can be seen in the diagram that due to the presence of proeutectoid phase, start line shifts towards left and nose of TTT diagram appear prior to 1 sec. So hardenability of both hypo and hyper eutectoid steels are inferior to eutectoid steels. In the microstructure along with normal pearlite phase there will be proeutectoid phase. It can be observed from the TTT diagram of hypereutectoid steel that martensite finish line appears below room temperature. So retained austenite will appear while quenching the sample to room temperature. To produce uniform phase martensite, such sample are quenched in liquid nitrogen and the process is called cryogenic treatment of materials.

2.22 HARDENABILITY CURVES JOMINY END QUENCH TEST

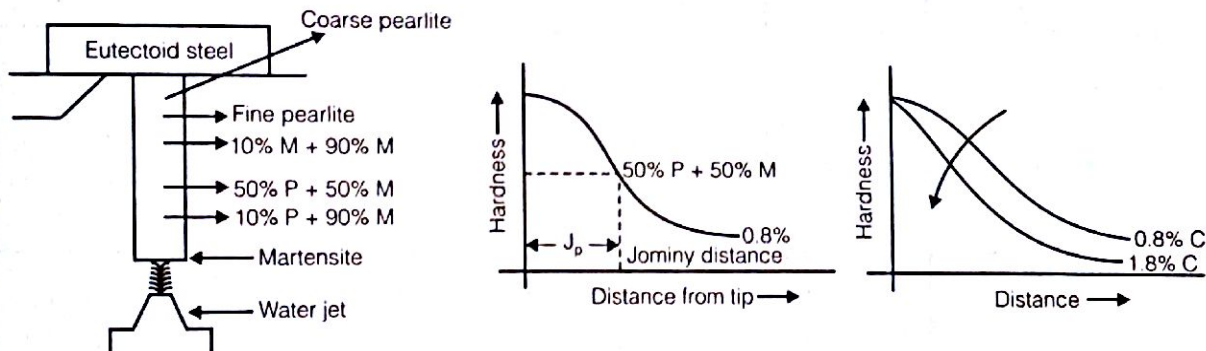


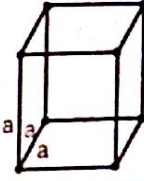
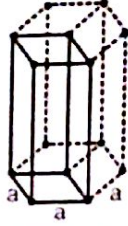
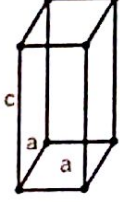
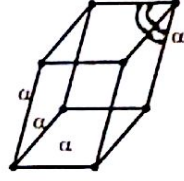
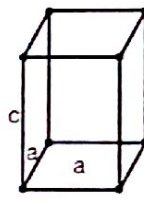
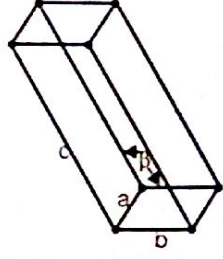
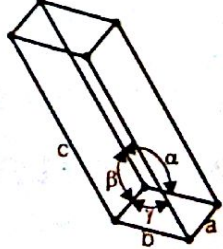
Fig. 2.51 : Jominy and Quench test

As shown in figure (2.51), austenite sample is quenched on one side and different cooling rates will be experienced by the sample as we go away from the tip. Gradually the percentage of martensite will decrease and percentage of pearlite will increase. Upon plotting the curve between hardness and distance from the tip the resulting curve is called hardenability curve. On this curve, the distance upto which there is a mixture of 50% pearlite and 50% martensite is called Jominy distance.

2.23 CRYSTAL SYSTEMS

Every material is a building material block to some unit called bravious lattice. There are 7 different type of bravious lattices

Lattice Parameter Relationships and Figures Showing Unit Cell Geometries for the Seven Crystal Systems :

Crystal system	Axial	Interaxial Angles Relationship	Unit Cell Geometry
Cubic	$a = b = c$	$\alpha = \beta = \gamma = 90^\circ$	
Hexagonal	$a = b \neq c$	$\alpha = \beta = 90^\circ, \gamma = 120^\circ$	
Tetragonal	$a = b \neq c$	$\alpha = \beta = \gamma = 90^\circ$	
Rhombohedral	$a = b = c$	$\alpha = \beta = \gamma \neq 90^\circ$	
Orthorhombic	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90^\circ$	
Monoclinic	$a \neq b \neq c$	$\alpha = \gamma = 90^\circ \neq \beta$	
Triclinic	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90^\circ$	

Atomic packing factor (APF) is defined as the percentage volume of unit covered by the atoms. The coordination number is defined as the no. of atoms that are in the physical proximity of any atom. Let us elaborate on cubic structure.

2.23.1 Simple Cubic

There is one atom at each corner and this atom is shared by 8 unit cells. So number of atoms per unit cell

$$n = \frac{1}{8} \times 8 = 1$$

size of unit cell (lattice constant) = a

$$APF = \frac{1 \times \frac{4}{3} \times \pi r^3}{a^3} \text{ also } a = 2r$$

So

$$APF = 0.52$$

The coordination number of simple cubic is = 6.

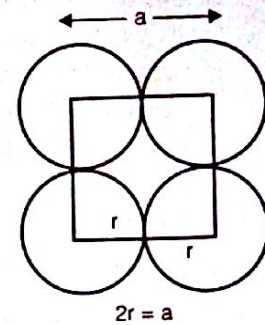


Fig. 2.52

2.23.2 Body Centred Cubic (BCC)

Along with one atom at each corner there is atom at the centre of each unit cell which is in physical contact with all the corner atoms.

$$n = \frac{1}{8} \times 8 + 1 = 2$$

$$APF = \frac{2 \times \frac{4}{3} \times \pi r^3}{a^3}$$

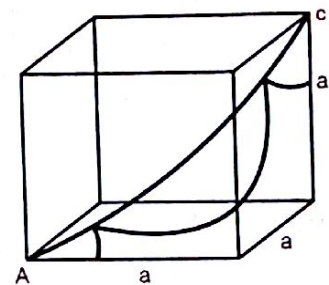
⇒

$$4r = a\sqrt{3}$$

So

$$APF = 0.68.$$

The coordination number of bcc is 8.



AC Body Diagonal
 $AC^2 = a^2 + a^2 + a^2$

Fig. 2.53

2.23.3 Face Centred Cubic (FCC)

Along with one atom at each corner there is an atom on each face.

$$n = 8 \times \frac{1}{8} + 6 \times \frac{1}{2} = 4$$

$$APF = \frac{4 \times \frac{4}{3} \times \pi r^3}{a^3}$$

⇒

$$4r = a\sqrt{2}$$

$$APF = 0.74$$

The coordination number FCC is 12.

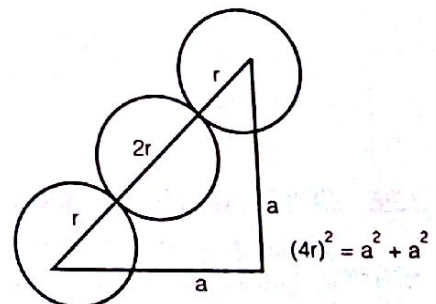


Fig. 2.54

2.24 MECHANISM OF CRYSTALLIZATION

Transition from liquid to the solid state takes place by nuclei formation and growth. Atoms in the material have both Kinetic energy and Potential energy. Kinetic energy is related to the speed at which the atom moves and it is a function of temperature. It is because at a higher temperature diffusion phenomenon will be predominant which is caused by higher Kinetic energy of atoms. Potential energy is related to the distance between the atoms. Kinetic energy of atoms in the liquid as well as solid phase is same but there is a significant difference in the Potential energy.

If there is an alloy with eutectic composition (or) there is a pure material, mechanism of crystallization is called skin forming. At the boundary of the liquid metal since the temperature is low, solid will nucleate. This solidification front will move towards the centre and there will be systematic crystal growth from the surface towards the centre.

If mushy zone appears in the alloy nucleation will take place not only on the surface but in the liquid region as well. In this case there will be multi directional crystal growth called dendrite formation. If the cooling rate of the liquid metal is slow nucleation will take place at smaller number of places which produces coarse grain structure. If the cooling rates are very high, nucleation will take place at large number of places, which produces fine grain structure.

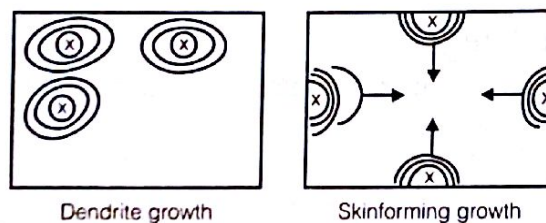


Fig. 2.55 : Dendritic growth and skin forming

2.25 METHODS FOR MEASUREMENT OF GRAIN SIZE

1. **Comparison Method** : Two work pieces are magnified with equal magnification factor approximately 100 and the size of grain is compared. But we can't quantify the coarseness and fineness of the grain structure by this method.
2. **Intercept (Heyn) Method** : The number of grains intersected by one or more straight lines. Grains touched by the ends are counted as 1/2 grains only such measurements are done in all the three directions. In the similar way dislocation density is also defined i.e. number of dislocation per unit length. But in the intercept method the grain density is defined as length of line divided by average number of grains.
3. **Planimetric Method** : (Jefferies Method) A circle (or) square of area 5000 mm² is drawn over the specimen. Grains falling completely inside the area are counted as full and intersected grains are counted as 1/2. Average number of grains per unit area is calculated by this method.

2.26 CRYSTAL DIRECTIONS

Crystal directions are represented by bracket [] and whatever is written in the bracket can be considered as 3D co-ordinate point. After identifying the point it has to be joined with origin to draw the crystal direction. Bar on any axis indicate negative value. Some of the directions are drawn as under :

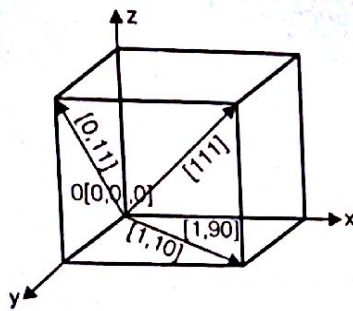


Fig. 2.56

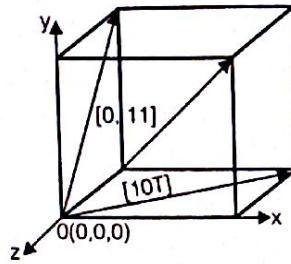


Fig. 2.57

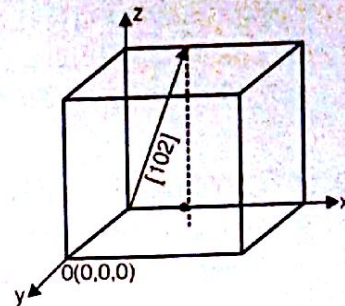


Fig. 2.58

The maximum number appeared in the bracket can be considered as the size of unit cell. The term linear density is defined as the number of atoms appeared on any direction to the length of direction vector. Here the atom is designated by its diameter.

Example : 2.9

Linear density of simple cubic structure along direction [100].

Solution :

Since complete atom appears along [100].

$$\text{Linear density} = \frac{1}{a}$$

Example : 2.10

Linear density of FCC along [110].

Solution :

Since 2 atoms will appear along that direction and the length of direction is $a\sqrt{2}$.

Solution :

$$\begin{aligned} \text{So} \quad \text{Linear density} &= \frac{2}{a\sqrt{2}} \\ &= \frac{\sqrt{2}}{a} \end{aligned}$$

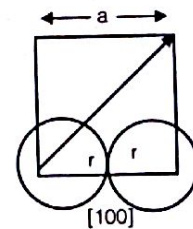


Fig. 2.59

Example : 2.11

Linear density of bcc along [111].

Solution :

Since 2 atoms appear along this direction. So

$$\text{Linear density} = \frac{2}{a\sqrt{3}}$$

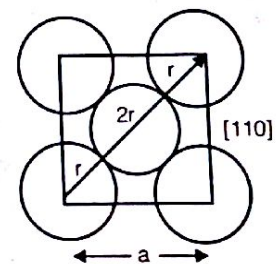


Fig. 2.60

Family of directions in the unit cell defined as all those possible directions in the unit cell which has same linear density are called family and are represented by symbol $\langle \rangle$.

$\langle 100 \rangle$ family is [100], [010], [001], [100], [010], [001]

$\langle 110 \rangle$ family is $[110]$, $[T10]$, $[1T0]$, $[TT0]$, $[101]$, $[T01]$, $[10T]$, $[T0T]$, $[011]$, $[0T1]$, $[01T]$, $[0TT]$

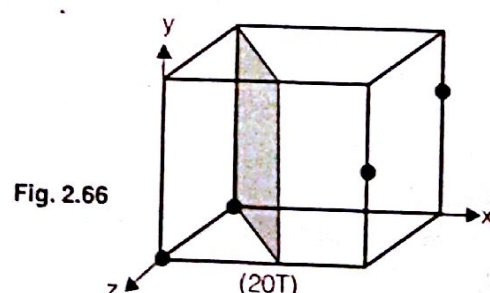
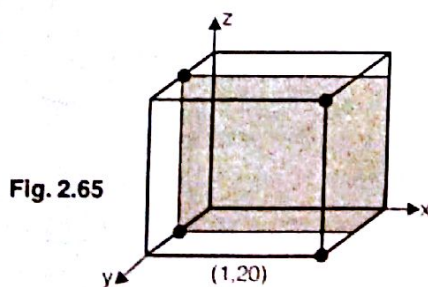
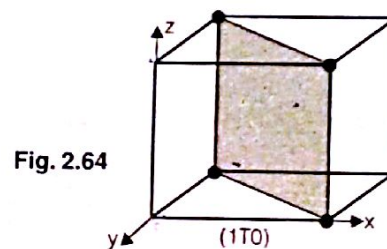
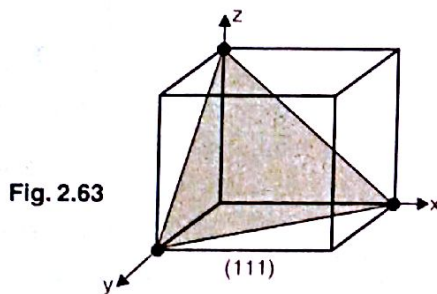
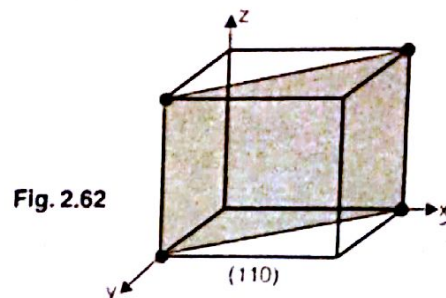
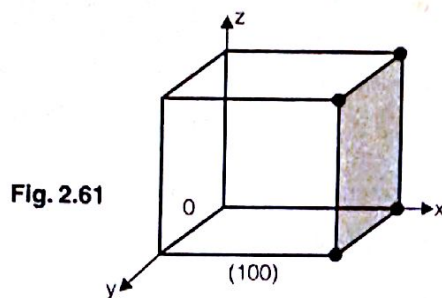
$\langle 111 \rangle$ family is $[111]$, $[T11]$, $[1T1]$, $[11T]$, $[TT1]$, $[T1T]$, $[1TT]$, $[TTT]$

If it is tetragonal structure there will be different linear density along z directions. So in this unit cell

$\langle 100 \rangle$ family is $[100]$, $[010]$, $[T00]$, $[0T0]$ only

2.27 CRYSTAL PLANES

Crystal plane is represented by symbol () and the quantities written inside are miller indices i.e. reciprocal of intercepts. Following is the representation of some of the planes.



$$\text{Planar density} = \frac{\text{No. of atom on a plane}}{\text{Area of plane}}$$

and number of atoms here are defined by cross-section area of the atom.

Example : 2.12

Planar density of (100) plane of simple cubic structure is $\frac{1}{a^2}$.

Example : 2.13

Planar density of (100) plane of fcc structure is $\frac{2}{a^2}$.

Example : 2.14

Planar density of (110) plane of bcc structure is $\frac{2}{a^2\sqrt{2}} = \frac{\sqrt{2}}{a^2}$.

Family of plane is defined as all those possible planes inside the unit cell which has same planar density and is represented by $\{ \}$. Similar to crystal direction

$\{ \}$ have 6 members

$\{ \}$ have 12 members

$\{ \}$ have 8 members.

A number of planes can be drawn with same miller indices in different unit cells. These planes will be parallel to each other. The distance between these 2 planes is called interplanar distance (d_{hkl}).

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

2.28 CREEP

It is defined as time dependent permanent deformation of materials when subjected to constant load or stress and it becomes important at a temperature beyond recrystallization. As soon as the material is loaded, some strains will appear in the material called instantaneous creep. This creep is similar to elastic strains and as soon as load is removed the strains will recover. In the primary creep region the strain rate decreases because due to work hardening material becomes stronger. In the secondary creep region a balance is achieved between recrystallization and work hardening. So almost constant strain rates are observed.

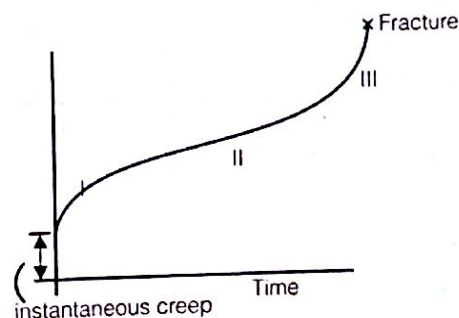


Fig. 2.67 : Creep Curve

But there will be a limit upto which work hardening can take place and in the tertiary creep regular recrystallization phenomenon takes over giving rise to sudden increase in strains and finally material breaks. By increasing the temperature the creep curve shifts as shown in figure because higher is the temperature, more predominant recrystallization phenomenon will be discussed as

before that grain boundary material is at a higher energy level, so at elevated temperature there is a tendency in the material to be low. So finer the grain structure lower will be the creep resistant.

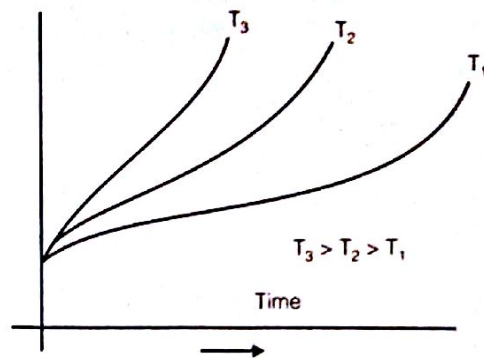


Fig. 2.68 : Variation of creep curve with temperature

2.29 TENSILE TEST

Tensile tests are being carried out to find out the mechanical properties of material. Samples are prepared generally according to ASTM standards and loaded in a UTM machine. Once the stress goes beyond the yield strength there will be decrease in cross-section area hence increase in stress. This increase in stress is compensated by increase in strength by work hardening. A unique neck will appear (anywhere in the parallel length) at a point of plastic instability where the increase in strength due to work hardening fails to compensate for the decrease in cross-sectional area. Gradually the sample fails like cup and cone fractures.

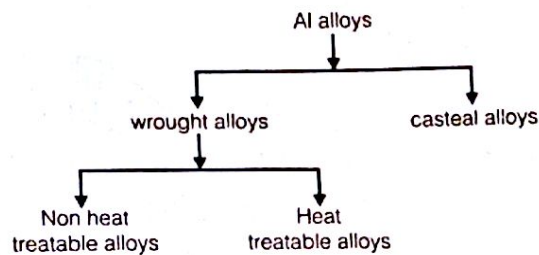
2.30 HARDNESS TESTS

Following is the comparison of different tests to quantify hardness

Test	Indenter	Measurement	Load (P)	Formula
Brinell hardness test	Ball of 10mm Hardened Steel	Area of indentation	500 Kg for soft material to 3000 kg for hard material	$BHM = \frac{2P}{\pi D [D - \sqrt{D^2 - d^2}]}$ D = dia of ball d = dia of indentation
Vickers hardness	Diamond pyramid of 136°	Area of indentation	5 to 120 Kg	$VH = \frac{1.854 P}{d_1^2}$ d ₁ = diagonal size of indentation
Rockwell hardness	Ball of 1.58 mm diameter for soft materials and cone of 120° with spherical tip of 0.2 mm radius for hard material	Depth of indentation	60 - 150 Kg	B scale = $\frac{130 - \text{depth}}{0.002}$ C scale = $\frac{100 - \text{depth}}{0.002}$

2.31 ALUMINUM ALLOYS

The addition of small quantities of various elements in aluminum greatly improves the mechanical properties. In aeroplanes and other structures the extreme lightness of the alloy enables much greater volume to be used for a given weight. Aluminium-alloys has coefficient of linear expansion twice to that of cast irons or steels and allowance has to be made when aluminium has to be casted. The corrosion resistance of Aluminium and its alloys is quite high.



2.31.1 Non heat treatable Al alloys

These alloys include Al-Mn (1.3% Mn) and Al-Mg (2.5-5% Mg). Al-Mn alloys have structure comprising the solid solution of Mn in Al and forms the compound $MnAl_6$. This alloy is strengthened by work hardening. Al-Mg alloys are the binary alloys of Al and Mg but most of the Al-Mg alloys are single phase in structure. All these alloys have comparatively low strength and high ductility and good weldability

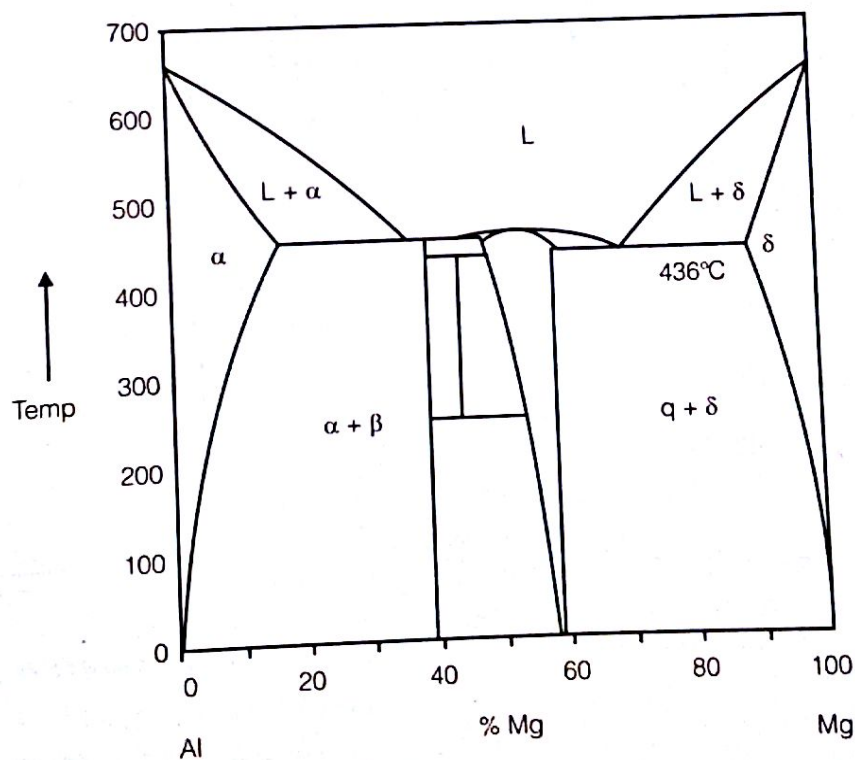


Fig. 2.69 : Al-Mg Phase Diagram

2.31.2 Heat treatable wrought alloys

Any alloy of Al which produces phase diagram similar to Al-Cu with % Cu less than 5.5% can be heat treated. Impurity of Cu is added in Al less than 5.5%. This alloy is heated to a temperature between $T_{\min}$ - $T_{\max}$ so that a uniform phase α appears in the sample. The sample is then quenched to room temperature. As a result of that Cu freezes in the structure of Al.

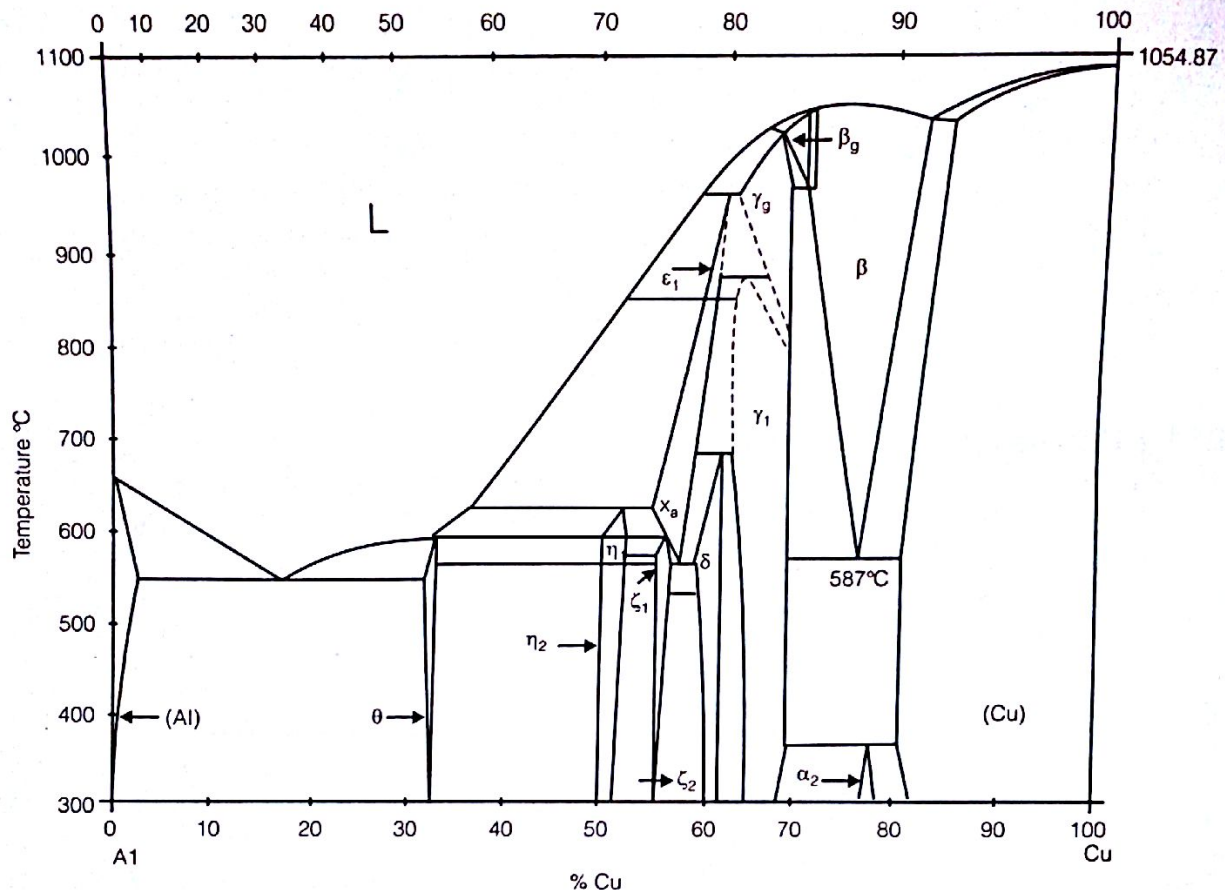


Fig. 2.70 : Al-Cu phase diagram

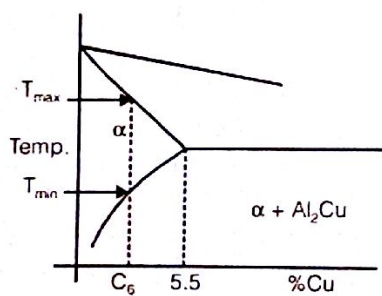


Fig. 2.71 : Portion of Al-Cu phase diagram

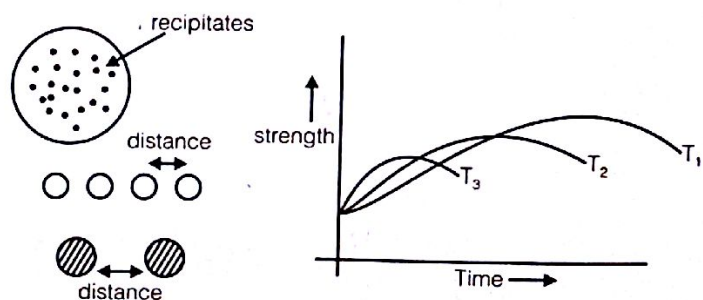


Fig. 2.72 : Age hardening

As the time passes precipitate start forming in the sample. These precipitate creates an obstacle in the movement of dislocation. This increases the strength. This phenomenon is called age (precipitation) hardening. As the time passes more and more precipitates nucleate. This decreases the average distance between the precipitates and hence dislocation will meet more number of

obstacles. So the strength of material keeps on increasing. Since Cu in Al is limited quantity so nucleation stops this refers to the peak strength. Later on smaller precipitates are combining together and forming bigger precipitates, this increases the distance between precipitates and hence strength of sample will decrease. This period on the curve is called overaging. Aging performed at room temperature is called natural aging and when it is performed at elevated temperature is called artificial aging. It can be seen from the figure (2.72) that as temperature increases the peak strength of material decreases and simultaneously material becomes stronger in lesser time period. The reason is that higher the temperature more will be the diffusion and hence the rate of precipitates and rate at which smaller precipitates are combining, both will be accelerated.

Rapid cooling after heating produces CuAl_2 precipitates from the α -solid solution and this single phase solid solution will be retained at room temperature. Such a solid solution is supersaturated and therefore unstable. The atom is sufficiently mobile at the temperature of the medium in which the alloy is held, the supersaturated solid solution is spontaneously decomposes. This process of returning the supersaturated solid solution to a more stable condition occurs in aging as well. Lowering the temperature restricts aging and may completely suppress it.

No decomposition of the solid solution is observed in natural Aging, since there is no precipitation of the excess phase from the supersaturated solution. What actually occurs is the collections of solute atoms of Cu in definite planes of the crystal lattice and the formation of zones rich in Cu-atoms. These zones with increased concentration of solute elements have the form of extremely thin disc's several atom layer's thick and can only be observed by X-rays analysis.

This type of change in solid solution of alloys, undergoing natural Aging is accompanied by pronounced distortion of the crystal lattice and this increases the strength. Since the solid solution does not decompose in natural Aging and the alloy will retain sufficient ductility and corrosion resistance.

When the alloy is subject to artificial aging at $100\text{--}150^\circ\text{C}$ and higher temperatures, dispersed lamellar particles of an intermediate phase which causes strengthening are precipitated at the places where there is increased concentration of the solute atoms. This intermediate phase does not appear in composition from the stable CuAl_2 phase but has a distorted tetragonal lattice. If the alloy is held for a long period of time at the above temperature or if the temperature is raised to 250°C or higher coagulation of the particles formed at the centres of decomposition is observed and the intermediate phase becomes stable. This is called over Aging.

The most important and extremely use alloys that are strengthened by hardening and subsequent aging are duralumin, avail and other special purpose alloys. These alloys contains 2.6-4.9% Cu, 0.25 – 1.5 % Mg, 0.5 -0.8 % Mn. The alloy 4.3% Cu, 0.6% Mg and 0.6% Mn is **normal duralumin** while the alloys containing higher percentages of Cu-Mg and Mn are high strength alloys but have lower ductility and therefore are difficult for hot and cold working. Alloys with lower percentages of Cu-Mg and Mn belongs to low alloys class of duralumin and are used for rivets. These alloys have relatively low strength but high ductility and malleability which help in riveting operation. The mechanical properties of duralumin are sharply increased after heat treatment. A necessary component of all duralumin alloy is Mn which improves corrosion resistance.

Fe to some extent and Si are impurities of duralumin alloys. Fe is a harmful impurity and by forming the compound $(\text{Mn, Fe})\text{Al}_6$, Fe considerably reduces the strength and ductility. Another Fe compound comprising both Cu and Al reduces the strengthening effect of aging. Therefore Fe-content should never exceed 0.5 – 0.6%. To a certain extent silicon eliminates the harmful effects of Fe by fixing it in the α -phase which can more easily be broken up while working. If the Fe content is low Si has a bad effect on natural aging.

Duralumin is available in sheet, strip, rod, shapes and wires. Sheet duralumin is usually clad to protect it against corrosion. Cladding consists in coating with pure Al (99.5%) clad Al is obtained by placing the duralumin ingot between two sheets of pure Al and rolling this pack or sandwich together this pack is hot rolled and reduced to a thickness of 6 mm and then cold rolled with intermediate process annealing operations.

Duralumin and similar other alloys may be comparatively easily hot and cold rolled, forged, formed and have good machinability. Intermediate annealing operations have temperature between 350°C-370°C and used in cold rolling.

The heat treatment for strengthening duralumin consist of :

1. Hardening followed by water quenching
2. Natural aging
3. Recovering i.e. heating for a short time (20-40°C) for 250-270°C after natural aging to restore the properties.
4. Strain hardening or work hardening

Avial : It contains 0.4-0.9% Mg, 0.5-1.2% Si and 0.2-0.6% Cu and it is heat treated. The heat treatment consist of heating to 530-540°C quenching in water and subsequent natural aging or artificial aging at 150-160°C for 12-16 hrs. Aging must be conducted directly after quenching otherwise the strengthening effect is reduced various semifinished products such as sheets, pipes, shapes etc are made form avail.

High strength Al-alloys : It contains 6% Zn 2.3% Mg 1.7% Cu and 0.4% Mn. After hardening by heating to 465 – 475°C and water quenching and subsequent artificial aging for 24 hrs at 120- 125°C. This alloy develops high strength and ductility. It has low machinability which may be improved by hardening and aging. It is comparatively low corrosion resistant.

Al-forging alloys : These alloys have different compositions ranging from 1.8-4.8% Cu, 0.4-1.8 % Mg, 0.4-1% Mn, 1-2.3% Mo, 0.5 - 1.6% Fe and 0.5-1.2 % Si. These alloys are used to manufacture machine parts such as pistons, screw blades, crank cases, rings corers, discs etc. Forging of these alloys are subjected to heat treatment which consists in heating to 510-520°C. Quenching in water and aging at 150-160°C for 12-18 hrs. Most Al alloys are forged at temperature 470°C and 430° C.

2.31.3 Al – base Casted Alloys

The following alloys are generally used :

1. **Alloys based on Al-Si system** called **silumin alloys** which contain 8 – 13% Si, 0.17 – 3% Mg and 0.25 – 0.5% Mn. A typical silumin is the eutectic alloy which is distinguished for its high castability (high fluidity and low shrinkage), good corrosion resistance, high ductility and low specific gravity (2.6 gram/cm³). The alloy is non heat treatable and is strengthened by adding about 0.01% Na to melt just before casting. Silumin is modified by adding a mixture of 2/3 NaF and 1/3 NaCl and the amount added is 2% of the melt by weight. Other modifying mixture like 60% Na, 25% NaCl, 15% NaAlF₆, degasifies the alloy and removes oxide.

A disadvantage of silumin as a casting alloy is the porosity of the casting and it can be avoided by casting under pressure. The addition of Mg and Cu enables silumin alloys to be heat treated. Such alloys posses excellent casting properties but has a tendency to foam and porosity. The alloy has strength by modifying and subsequent heat treatment. The alloy can be easily machined and has a high corrosion resistance. It is used for large castings which are used to operate under heavy duty condition.

2. **Alloys based on the Al-Mg System** which contain 9.5 – 11.5% Mg and have comparatively poor castability. Special foundry procedures like application of special fluxes adding to the molding sand and degasification of the melt are required in casting. Due to its high mechanical properties good corrosion resistance and low weight. It is employed for castings of relatively simple form subject to dynamic loads in operation and expose to corrosive environment. This alloy is used only after heat treatment.
3. **Alloys based on Al-Cu system** which contains either 4-5% Cu or 7-14% Cu. The former possesses comparatively low castability but develops good mechanical properties after heat treatment. The latter is used without heat treatment. It has much better casting properties and a high strength which is retained up to 250-300°C but is less ductile.
4. **Alloys based on Al-Si-Cu system** which contains either 4.5-5.5% Si, 1-1.5% Cu, 0.35-0.6% Mg or 4.5-6% Cu and 2-3% Si. These alloys have good foundry characteristics. The latter of the two is used for sand mold permanent mold and die castings. Dense air tight castings are obtained which may be welded if required. The former heat treatable alloy is extensively used because its casting properties are good and it gives excellent service for large heavily loaded machine parts and parts used at elevated temperatures.
5. **Zn – Alumin alloys** which contains 6-9% Si and 10-14% Zn have excellent castability and can be modified to improve mechanical properties. These are used for castings of complex form requiring high mechanical properties. A disadvantage is its increased specific weight (2.93 gm/cc).

2.32 BRASSES

The alloys Copper and Zinc are generally called brasses. The equilibrium diagram of Copper and Zinc is shown in figure.

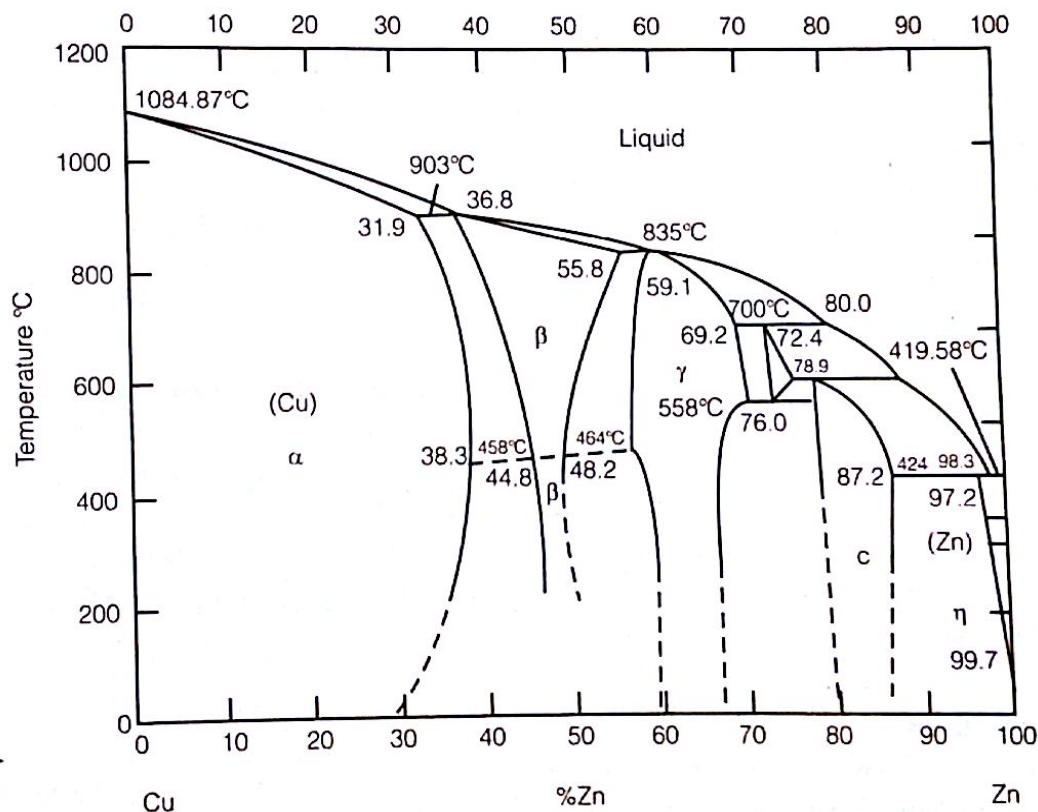


Fig. 2.73 : (Al-Zn phase diagram)

As shown in Fig. (2.73) Cu-containing up to 39% Zn has a single phase structure consisting of crystals of the solid solution of Zn in Cu (α - phase). A new structural component i.e. β phase appears in alloys containing from 39-50% Zn. β -phase is also a solid solution. The solvent in this case is not the pure metal but an electron compound Cu-Zn having a space centred lattice (cubic). The β -phase has a disordered distribution of atoms at high temperature upon lowering the temperature to 453-470°C. The Cu and Zn atoms in the solid solution acquire an ordered structure. Which is designated as beta. It is clear from Fig. (2.73) that the β solid solution has a wide range of homogeneity at high temperatures. It decomposes as the temperature is lowered and crystals of the excess α and γ phases begin to precipitate from the solution. The γ -phase formed in high Zn alloys is a very brittle compound, has a complex cubic lattice and therefore brasses intended for room temperature service consist completely of the α -phase (α brasses or of the mixture ($\alpha + \beta$ brasses)).

Brass acquires maximum relative elongation at a Zn content from 30-32% which approximately coincides with the boundary between the α -phase and ($\alpha + \beta'$) phase regions. The α phase is the most ductile structure when the β' phase appears in the structure. The relative elongation is reduced and reaches very low values when the zinc content corresponds to the point at which the β' phase structure is formed. Upon increasing the zinc content to 45-47%, the tensile strength first increases and then rapidly decreases.

The α -brasses have good workability at room temperature. They are much less ductile at temperature from 300-700°C. Brasses are strain hardened by cold working i.e. rolling drawing etc. Their ductility may be restored by annealing at 500-700°C. In ductility the ($\alpha + \beta'$) brasses are inferior to α -brasses for hot working the ($\alpha + \beta'$) brasses are heated to the range of homogeneous β solution which possesses high ductility.

When stored for a long period of time or when exposed to a corrosion reactive agent, Brass disintegrates and failure of the metal is known as seasonal cracking. This may be eliminated by annealing the strain hardened brass at 200-300°C for several hours. The considerable toughness makes the brass more difficult to machine. A small amount of lead is often added to improve machinability. Such alloys are called leaded or free cutting brasses. Brasses are used in the sheet or strip form for products made by deep drawing for radiators, curling rings, connection pipes, tubings etc. Some types are used as rolled or extruded bar stock for making machine parts such as bushings, nuts, rings etc.

In addition to plain brasses i.e. Cu and Zn alloys and **muntz metal, (Cu-Zn-Pb)**, special brasses find wide applications in industries. There are complex alloys that differ from ordinary brasses in structure and properties. This is due to the addition of various alloying elements like Sn, Si, Mn, Al and Fe. These are used for castings and tubings for ship building and general engineering casting for heavily loaded components like large worms, large critical castings in ship buildings, load carrying components for aircraft automobiles and ship building, bearings, bushings etc.

2.33 BRONZES

Alloys of Cu with all other elements except Zn are called bronzes. Zn may be a constituent but only together with other components and in relatively small amount.

2.33.1 Tin-bronzes

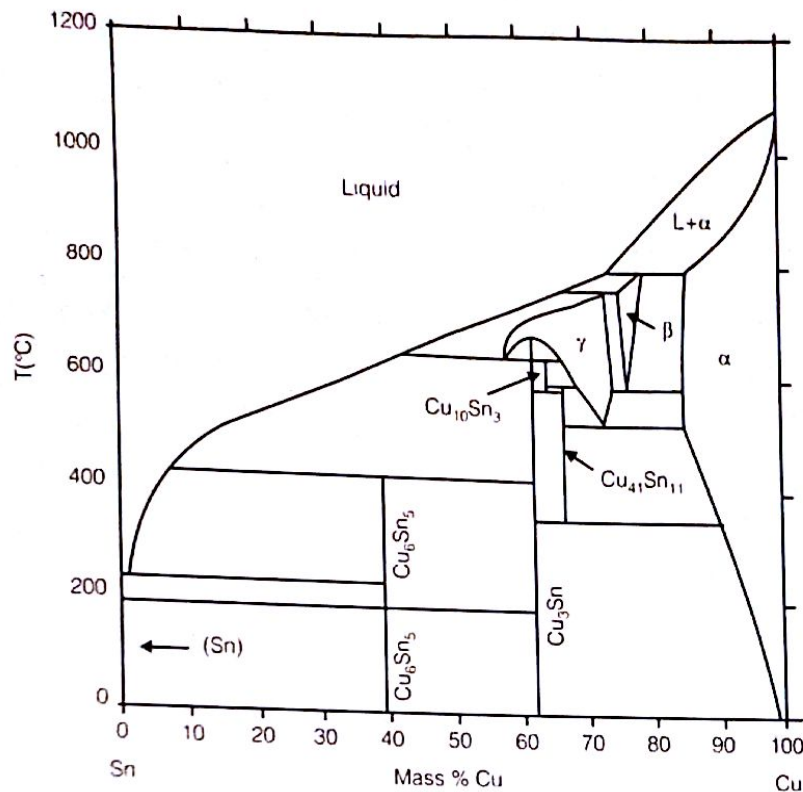


Fig. 2.74 : Cu-Sn phase diagram

The Cu-Sn equilibrium diagram is shown in figure (2.74) where the α -phase is a solid solution of Sn in Cu. The diagram shows that there are several peritectic transformations and two eutectoid transformations in the solid state at 587°C . The β -phase undergoes a eutectoid decomposition and forms a mixture of β and γ phases while at 520°C the γ -phase crystals decompose into the α -phase and $\text{Cu}_{31}\text{Sn}_8$.

At a temperature of about 350°C the electron compound $\text{Cu}_{31}\text{Sn}_8$ decomposes into the α -phase and the compound Cu_3Sn . This transformation occurs only in a state of complete equilibrium. Under actual cooling conditions the structure of bronze consists of the phase α and Cu_3Sn . Only the right-hand side of the diagram is of practical importance which corresponds to the formation of the α -solid solution of Sn in Cu. The tensile strength of bronze increases until the tin content reaches 20%. It drops sharply upon further increase in tin content due to the presence of a considerable quantity of eutectoid which contains the brittle compound $\text{Cu}_{31}\text{Sn}_8$. The relative elongation increases up to a Sn content of 5-6% and then it drops sharply as the eutectoid begins to appear in the structure; consequently only bronzes containing up to 5-6% Sn are workable.

Sn-bronzes have good capability and are widely used in the foundry. A special feature of bronzes is anti-friction property. Zn may be added to Sn bronzes to allow the Sn-content to be reduced which in turn reduces the cost and improves castability.

Machinability of bronze may be improved by adding lead (Pb). Phosphorus acts as a de-oxidizer when added to bronze, as well as an element for strengthening the alloy. An addition of about 1% P improves castability and increases the mechanical and anti-friction property. Wrought tin bronzes undergo heat treatment consisting of annealing at $600-650^{\circ}\text{C}$ as an intermediate operation.

in cold working or as a final operation to provide the required properties. In the semifinished products like sheet and strip. Bronzes containing a large quantity of expensive Sn are replaced by cheaper alloys. Low Sn bronzes to which Zn, Pb, Ni and other element have been added is used for fittings and for antifriction components.

2.33.2 Tin Free Bronzes

As Sn is very expensive, various grades of Sn free bronzes have found extensive applications in industry along with tin bronzes. Most tin free bronzes have higher mechanical properties than tin bronzes, better corrosion resistance excellent antifriction properties etc. Their machinability and castability are however inferior to those of tin bronzes.

Al bronzes are extensively used. The effect of Al-addition on the machinability properties of Cu is quite substantial. Bronzes containing upto 6-8% Al can be successfully worked either hot or cold. The mechanical properties of these bronzes are considerably improved by stress hardening. Bronzes containing 10% Al can only be worked at high temperatures but are easily cast and are much used as foundry materials. All Al bronzes have good corrosion resistance. An addition of Fe to these materials refine their structure and substantially improves their mechanical properties. A better combination of mech properties is obtained by normalizing or hardening which consist in heating to 650°C followed by water quenching. The high mechanical properties developed at room temperature by the addition of Ni are retained at elevated temperature as well. A desirable addition of bronze in Mn, which improves both mechanical and fabricating properties.

2.33.3 Si-Bronzes

In certain application e.g. for spring type components tin bronzes may be replaced by cheaper Si-bronzes alloyed in Mn which also have high mech properties.

2.33.4 Be-Bronzes

They develop exceptionally high mechanical properties after heat treatment. After hardening by heating to 800°C and water quenching these alloys acquire high tensile strength and relative elongation. A subsequent tempering or age hardening at 350°C for 1-2 hrs raises the tensile strength to almost 3 times, though the relative elongation falls to quite low values. Be-bronze is an excellent material for springs due to its high elasticity and resistance to fatigue and corrosion. At the same time it has a high hardness and wear resistance. A disadvantage is its high cost.

2.33.5 Leaded Bronzes

It is applied for the bearing lines for machinery operating at high speeds. In the solid state Pb and Cu are almost insoluble in each other. The structure of these bronzes consist of crystals of Cu and soft Pb. The excellent antifriction property are due to this structure. Leaded bronzes give satisfactory service as bearings subject to high specific pressures and speeds since their fatigue limits reach very high values and their resistance to impact loads exceeds that of other bearing materials. A disadvantage of leaded bronzes is their tendency to segregate. To avoid this special casting procedures such as additions of special elements are required. A Cu base alloy with nickel called cupronickel is used in industry as a corrosion resistant material at elevated temperatures and can also be used in surgical equipments, kitchen utensils coins and various ornaments. Cupro-nickel with 30% Ni is widely used for navel condenser tubes due to its good resistance against corrosion by sea water. A Cu alloy containing 40% Ni and 1.5% Mn called constantan is widely used for rheostats, thermocouples and heating devices operating at moderately high temperatures.

POINTS TO PONDER

Nonferrous Metals and Alloys

1. **Aluminium**
- Prepared from bauxite
 - Good electrical conductivity
 - High resistance to corrosion and is non-toxic

Al. Alloys

Duralium

Composition

3.5 - 4.5% Cu, 0.4 - 0.7%

Application

Forging stamping bars, tubes, rivets, sheets

γ-alloy

Mn & Mg + Al

3.5 - 4.5% Cu, 1.2 - 1.7% Mg

Piston and components of aeroengines

2. Copper

- Copper ore is pyrites
- It is soft, malleable, ductile, flexible, very tough and strong.

Copper Alloys

Composition

Application

Al bronze

90% Cu, 10% Al

Jewellery decorative purpose

Babbitt Metal

88% Sn, 8% Sb
4% Cu

Used in bearing metals that

Subjected to high pressure and load

Tin Bronze

75 - 95% Cu,
5 - 25% Sn

Utensiles, bearings

Bushes, sheet rod, wires, articles

Phosphorous

93.7% Cu,
6% Sn

Heavy loads, worm

Wheels, gears

Bronze

0.3% P

Nuts for machine screws, springs

Brass

50% Cu,
50% Zn

Hydraulic fitting,

Pumps, lining, utensils, bearing, bushes etc.

3. Lead

- Extracted from lead ore "galena".
- It is soft malleable and ductile metal

Soft solder

Lead 37% + Tin 63%

Medium solder

Lead 50% + Tin 50%

Electrician Solder

Lead 58% + Tin 42%

Plumbers Solder

Lead 70% + Tin 30%

4. Bearing Metals

Composition

Application

Copper-base

80% Cu

Harder and stronger

BM

10% Sn, 10% Pb

Babbitt BM

88% Sn
8% Sb, 4% Cu

High pressure

Load

Lead-Base

85% Pb

Light load

BM

10% Sb, 5% Sn

Pressure

Cadmium-base

at elevated temperature

BM

5. Copper - Tin alloys

Alloys	Composition	Application
Bronze		Boller, Tanks
Phosphorous- Bronze		Stoves
Silicon Bronze	96% Cu 3% Si, 1% Mg Zn	Strength and good Corrosion resistance are required
Gun Metal	88% Cu 10% Sn, 2% Zn	Boiler fitting Bushes, beam glands etc. (Zn for fluidity)
Bell Metal	80% Cu 20% Sn	Bells, gongs, utensil etc.
Manganese Bronze	Cu, Zn Pb, M	Bushes, Plungers Feed pump rods etc.

- 6. Zinc**
- The ore is zinc - blende (zince - sulphide) and calamine.
 - Low cost, corrosion resistance and alloying properties.

Alloys	Composition	Application
Brasses	50% Cu 50% Zn	Hydraulic fitting Pump lining utensils, bearing, bushes
Muntz Metal	60% Cu 40% Zn	Electrical equipment, fuses, bolts, rods, tubes, etc.
Admiralty brass	70% Cu 29% Zn, 1% Sn	Condenser Tubes

7. Nickel Alloys

Alloys	Composition	Application
Monel Metal	60%Ni, 38%Cu + Al & Mn	Rods, sheets, wire, welded tubing
German Silver	25 - 50% Cu, 10 - 35% Ni, 25 - 35% Zn	Utensil, electrical works
Inconel	75 - 80% Ni, 10 - 15% Cr	Resistance wire for electrical appliances

8. Other important alloys

- | | |
|----------------------|--|
| i. Timken alloy | - 10% W, 10% Co, 59% Ni, 9% Cr, 0.25% Fe |
| ii. Beryllium Bronze | - Be 1.5 - 2%, Sn 8%, + Rest Cu |
| iii. Elektron | - 12 - 13% Al, 0.03% Mn, 2% Zn, + Rest Mg |
| iv. Stellite | - 40 - 50% Co, 25 - 30% Cr, 15 - 30% W, 2 - 4% C |
| v. Cemented Carbide | - 10% TaC, 15% TiC, + Co |
| vi. UCON | - 50% Nb, 30% Ti, 20% W |

○○○○

PRACTICE QUESTIONS

1. In low carbon steels, presence of small quantities Mn improves
- | | |
|-------------------|-----------------|
| (a) weldability | (b) formability |
| (c) machinability | (d) strength |

2. Consider the following statements:

Addition of silicon to cast iron

1. Promotes graphite nodule formation
2. Promotes graphite flake formation
3. Increases the fluidity of the molten metal
4. Improves the ductility of cast iron

Of these statements

- | | |
|-------------------------|-------------------------|
| (a) 1 and 4 are correct | (b) 2 and 3 are correct |
| (c) 1 and 3 are correct | (d) 3 and 4 are correct |

3. Match List-I (Heat treatment) with List-II (Effect on the properties) and select the correct answer using the codes given below the lists:

List-I

- A. Annealing
- B. Nitriding
- C. Martempering
- D. Normalising

List-II

1. Refined grain structure
2. Improves the hardness of the whole mass
3. Increases surface hardness
4. Improves ductility

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	1	3	4	2
(c)	4	2	1	3
(d)	2	1	3	4

4. Eutectoid reaction occurs at

- | | |
|-----------|------------|
| (a) 600°C | (b) 723°C |
| (c) 114°C | (d) 1493°C |

5. Match List-I (Name of Material) with List-II (% Carbon Range) and select the correct answer using the codes give below the lists:

List-I

- A. Hypo-eutectoid steel
- B. Hyper-eutectoid steel
- C. Hypo-eutectic cast iron
- D. Hyper-eutectic cast iron

List-II

1. 4.3 – 6.67
2. 2.0 – 4.3
3. 0.8 – 2.0
4. 0.008–0.8

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	1	3	4	2
(c)	4	1	2	3
(d)	1	2	3	4

6. Which one of the following sets of constituents is expected in equilibrium cooling of a hypereutectoid steel from austenitic state ?

- (a) Ferrite and pearlite (b) Cementite and pearlite
(c) Ferrite and bainite (d) Cementite and martensite

7. Match List-I (Alloy) with List-II (Use) and select the correct answer using the codes give below the lists:

List-I

- A. Low carbon steel
B. Hadfield manganese steel
C. Constantan
D. Babbitt alloy

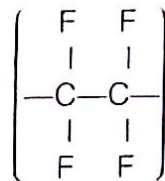
List-II

1. Bearing
2. Thermocouple
3. Wire nails
4. Bulldozer blades

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	3	4	1	2
(c)	3	2	1	4
(d)	3	4	2	1

8. The structure of a polymer is shown in the given figure. This polymer finds special application in



- (a) packaging (b) adhesives
(c) bearings (d) fertilizer

9. Addition of magnesium to cast iron increases its.

- (a) Hardness (b) Ductility and strength in tension
(c) Corrosion resistance (d) Creep strength.

10. 18/8 stainless steel contains

- (a) 18% stainless, 8% chromium (b) 18% chromium, 8% nickel
(c) 18% tungsten, 8% nickel (d) 18% tungsten, 8% chromium

11. Tin base white metals are used where the bearings are subjected to

- (a) large surface wear (b) elevated temperature
(c) light load and pressure (d) high pressure and load,

12. Alloy steel which is work hardenable and which is used to make the blades of bulldozers, bucket wheel excavators and other earth moving equipment contain iron, carbon and

- (a) chromium (b) silicon
(c) manganese (d) magnesium

13. Consider the following statements:

Thermosetting plastic are

1. Formed by addition polymerization
2. Formed by condensation polymerization
3. Softened on heating and hardened on cooling for any number of times
4. Modulated by heating and cooling

Of these statements

- (a) 1 and 3 are correct
(b) 2 and 4 are correct
(c) 1 and 4 are correct
(d) 2 and 3 are correct

14. Match List-I and List-II and select the correct answer

List-I

- A. Polyethylene
B. Polyurethane
C. Cyanoacrylate
D. Nylon

List-II

1. Adhesive
2. Film
3. Wire
4. Foam

Codes:

	A	B	C	D
(a)	2	4	3	1
(b)	4	2	3	1
(c)	2	4	1	3
(d)	4	2	1	3

15. Consider the following statements :

Fibre Reinforced plastic are

1. Made of thermosetting resins and glass fibre
2. Made of thermoplastic resins and glass fibre.
3. Anisotropic
4. Isotropic

Of these statements which are correct?

- (a) 1 and 4
(b) 1 and 3
(c) 2 and 3
(d) 2 and 4

16. During tensile-testing of a specimen using Universal Testing Machine, the parameters actually measured include

- (a) True stress and true strain
(b) Poisson's ratio and Young's modulus
(c) Engineering stress and engineering strain
(d) load and elongation

17. Consider the following statements:

When a metal or alloy is cold worked

1. It is worked below room temperature
2. It is worked below recrystallization temperature
3. Its hardness and strength increases
4. Its hardness increases but strength does not increase

Of these statements

- (a) 1 and 3 are correct
(b) 1 and 2 are correct
(c) 2 and 3 are correct
(d) 2 and 4 are correct

18. Which of the following pairs regarding the effect of alloying elements in steel are correctly matched?

1. Molybdenum : Forms abrasion resisting particles
2. Phosphorous : Improves machinability in free cutting steels
3. Cobalt : Contributes to red hardness by hardening ferrite
4. Silicon : Reduces oxidation resistance

Select the correct answer using the codes given below :

- (a) 2, 3 and 4 (b) 1, 3 and 4
(c) 1, 2 and 3 (d) 1, 2 and 4

19. Machines tool guideways are usually hardened by

- (a) vacuum hardening (b) martempering
(c) induction hardening (d) flame hardening

20. Guideways of lathe beds are hardened by

- (a) carburizing (b) cyaniding
(c) nitriding (d) flame hardening

21. A given steel test specimen is studied under metallurgical microscope. Magnification used is 100 X. In that different phases are observed. One of them is Fe_3C . The observed phase Fe_3C is also known as

- (a) ferrite (b) cementite
(c) austenite (d) martensite

22. Match List-I with List-II and select the correct answer using the codes given below the Lists:

List-I

- A. Toughness
B. Endurance strength
C. Resistance to abrasion
D. Deflection in beam

List-II

1. Moment area method
2. Hardness
3. Energy absorbed before fracture in a tension test
4. Fatigue loading

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	4	3	2	1
(c)	3	4	2	1
(d)	3	4	1	2

23. In metals subjected to cold working, strain hardening effect is due to

- (a) slip mechanism (b) twining mechanism
(c) dislocation mechanism (d) fracture mechanism

24. Match List-I with List-II and select the correct answer using the codes given below the Lists:

List-I

- A. Neoprene
B. Bakelite
C. Foamed poly-urethane
D. Araldite

List-II

1. Electric switches
2. Adhesive
3. Thermal insulator
4. Oil seal

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	1	4	2	3
(c)	4	1	3	2
(d)	1	4	3	2

25. Which one of the following materials is used for car tyres as a standard material?

- (a) Styrene-butadiene rubber (SBR)
(b) Butyl rubber
(c) Nitrile rubber
(d) Any one of the above depending upon the need

26. Which one of the following refractory materials is recommended for steel furnaces containing CaO slag?

- (a) Alumina
- (b) Silica
- (c) Magnesite
- (d) Fireclay

27. Which of the following properties of a solid are dependent on crystal imperfections?

- 1. Yield stress
- 2. Melting point
- 3. Semiconductivity
- 4. Ductility

Select the correct answer using the codes given below:

- (a) 1 and 3
- (b) 1, 3 and 4
- (c) 2, 3 and 4
- (d) 2 and 4

28. Which of the following components can be manufactured by powder metallurgy methods?

- 1. Carbide tool tips
- 2. Bearings
- 3. Filters
- 4. Brake linings

Select the correct answer using the codes given below:

- (a) 1, 3 and 4
- (b) 2 and 3
- (c) 1, 2 and 4
- (d) 1, 2, 3 and 4

29. Assertion (A) : The notch sensitivity of cast iron component is zero.

Reason (R) : Cast iron does not have yield point.

- (a) Both A and R are individually true and R is the correct explanation of A.
- (b) Both A and R are individually true but R is not the correct explanation of A.
- (c) A is true but R is false.
- (d) A is false but R is true.

30. Assertion (A) : Austenitic stainless steel contains 18% chromium and 8% nickel. Since it retains its austenitic structure at room temperature, it is called austenitic stainless steel.

Reason (R) : Chromium present in the steel improves its corrosion resistance by forming a thin film of chromium oxide on the surface.

- (a) Both A and R are individually true and R is the correct explanation of A.
- (b) Both A and R are individually true but R is not the correct explanation of A.
- (c) A is true but R is false.
- (d) A is false but R is true.

31. Match List-I (Alloying element in steel) with List-II (Property conferred on steel by the element) and select the correct answer using the codes given below the Lists:

List-I

- A. Nickel
- B. Chromium
- C. Tungsten
- D. Silicon

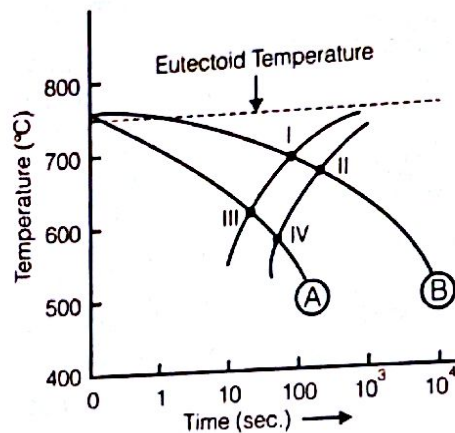
List-II

- 1. Corrosion resistance
- 2. Magnetic permeability
- 3. Heat resistance
- 4. Hardenability

Codes:

	A	B	C	D
(a)	4	1	3	2
(b)	4	1	2	3
(c)	1	4	3	2
(d)	1	4	2	3

32. Two cooling curves A and B for eutectoid iron-carbon alloy are superimposed on a continuous cooling transformation diagram as shown in the given figure. Fine pearlite microstructure is represented by the points labelled



- (a) I and III
(c) IV

- (b) II
(d) I

33. Match List-I (Alloys) with List-II (Applications) and select the correct answer using the codes given below the Lists:

List-I

- A. Chromel
B. Babbitt alloy
(Nitinol Steel) C. Nimonic alloy
D. High speed steel

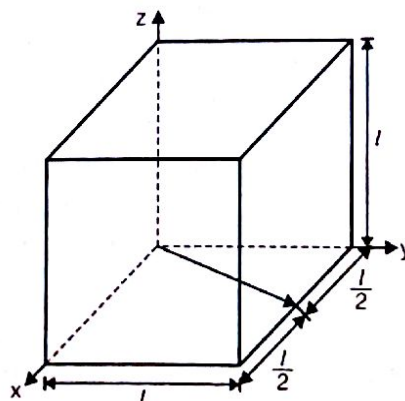
List-II

1. Journal bearing
2. Milling cutter
3. Thermocouple wire
4. Gas turbine blades

Codes: A B C D

- | | | | | |
|-----|---|---|---|---|
| (a) | 3 | 1 | 4 | 2 |
| (b) | 3 | 4 | 1 | 2 |
| (c) | 2 | 4 | 1 | 3 |
| (d) | 2 | 1 | 4 | 3 |

34. A unit cell of a crystal is shown in given figure. The miller indices of the direction (arrow) shown in the figure is



- (a) $[0\ 1\ 2]$
(c) $[2\ 1\ 0]$

- (b) $[0\ 2\ 1]$
(d) $[2\ 0\ 1]$

35. Match List-I (Material) with List-II (Structure) and select the correct answer using the codes given below the Lists:

List-I

- A. Charcoal
- B. Graphite
- C. Chromium
- D. Copper

List-II

- 1. F.C.C.
- 2. H.C.P.
- 3. Amorphous
- 4. B.C.C.

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	3	2	4	1
(c)	2	3	4	1
(d)	2	3	1	4

Direction: The following items consist of two statements, one labelled the 'Assertion (A)' and the other labelled the 'Reason (R)'. You are to examine these two statements carefully and decide if the Assertion (A) and the Reason (R) are individually true and if so, whether the Reason is a correct explanation of the Assertion. Select the your answer to these items using the codes given below and mark your answer sheet accordingly.

Codes:

- (a) Both A and R are individually true and R is the correct explanation of A.
- (b) Both A and R are individually true but R is not the correct explanation of A.
- (c) A is true but R is false.
- (d) A is false but R is true.

36. **Assertion (A):** Refining the grain size of polycrystal line material renders it harder and stronger.
Reason (R): Grain boundaries provide easy paths to dislocation motion.

37. **Assertion (A):** Plastic deformation in metals and alloys is a permanent deformation under load. This property is useful in obtaining products by cold rolling.
Reason (R): Plastic or permanent deformation in metal or alloy is caused by movement of dislocations.

38. **Assertion (A):** Carbon would form an interstitial solid solution with iron.
Reason (R): The atomic radius of iron is smaller than that of carbon.

39. **Assertion (A):** Cast iron is generally hard, brittle and wear resistant.
Reason (R): Cast iron contains more than 20% carbon and as such the percentage cementite in it is higher.

40. Consider the following statements:

The strength of the fibre reinforced plastic product

- 1. Depends upon the strength of the fibre alone
- 2. Depends upon the fibre and plastic
- 3. Is isotropic
- 4. Is anisotropic

Which of these statements are correct?

- (a) 1 and 3
- (b) 1 and 4
- (c) 2 and 3
- (d) 2 and 4

41. Match List-I (Crystal structure) with List-II (Atomic packing factor) and select the correct answer using the codes given below the lists:

List-I

- A. Simple cubic
B. Body-Centered cubic
C. Face-Centered cubic
D. Hexagonal close packed

List-II

1. 74%
2. 74%
3. 52%
4. 68%

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	4	3	2	1
(c)	3	4	1	2
(d)	4	3	1	2

42. Consider the following pairs of plastics and their distinct characteristics:

1. Acrylics...Very good transparency to light
2. Polycarbonate...Poor impact resistance
3. PTFE...Low coefficient of friction
4. Polypropylene...Excellent fatigue strength

Which of these statements are correct?

- (a) 2 and 3
(b) 1 and 3
(c) 1 and 4
(d) 2 and 4

43. Gibb's phase rule is given by

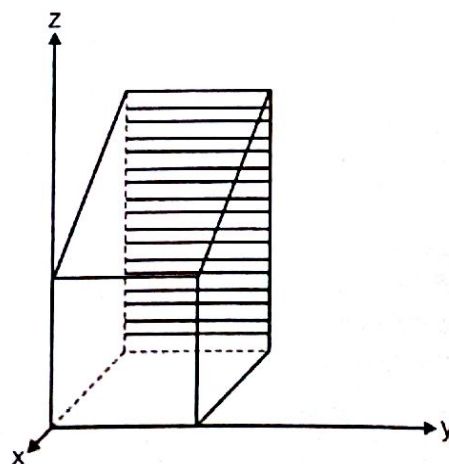
(F = number of degree of freedom

C = number of components

P = number of phases)

- (a) $F = C + P$
(b) $F = C + P - 2$
(c) $F = C - P - 2$
(d) $F = C - P + 2$

44. The set of Miller indices of the plane shown in the given figure is



- (a) (1 0 0)
(b) $(\bar{1} 0 0)$
(c) (1 0 1)
(d) (1 1 0)

45. Match List-I (Material) with List-II (Applications) and select the correct answer using the codes given below the Lists:

List-I

- A. Tungsten carbide
- B. Silicon nitride
- C. Aluminium oxide
- D. Silicon carbide

List-II

- 1. Abrasive wheels
- 2. Heating elements
- 3. Pipes for conveying liquid metals
- 4. Drawing dies

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	4	3	2	1
(c)	3	4	2	1
(d)	4	3	1	2

46. Heating the hypoeutectoid steels to 30°C above the upper critical temperature line, soaking at the temperature and then cooling slowly to room temperature to form a pearlite and ferrite structure, is known as
- (a) Hardening
 - (b) Normalising
 - (c) Tempering
 - (d) Annealing
47. In a eutectic system, two elements are completely
- (a) Insoluble in solid and liquid state
 - (b) Soluble liquid state
 - (c) Soluble in solid state
 - (d) Insoluble in liquid state
48. Assertion (A): Specimens for impact testing are never notched.
Reason (R): A notch introduces triaxial tensile stresses which cause brittle fracture.
49. Assertion (A): Carbon forms interstitial solid solution when added to iron.
Reason (R): The atomic radius of carbon atom is much smaller than that of iron.
- (a) Both A and R are individually true and R is the correct explanation of A.
 - (b) Both A and R are individually true but R is not the correct explanation of A.
 - (c) A is true but R is false.
 - (d) A is false but R is true.
50. Which one of the following features improves the fatigue strength of a metallic material?
- (a) Increasing the temperature
 - (b) Scratching the surface
 - (c) Overstressing
 - (d) Understressing
51. Percentages of various alloying elements present in different steel materials are given below:
- 1. 18% W; 4% Cr; 1% V; 5% Co; 0.7% C
 - 2. 8% Mo; 4% Cr; 2% V; 6% W; 0.7% C
 - 3. 27% Cr; 3% Ni; 5% Mo; 0.25% C
 - 4. 18% Cr; 8% Ni; 0.15 C
- Which of these relate to that of high speed steel?
- (a) 1 and 3
 - (b) 1 and 2
 - (c) 2 and 3
 - (d) 2 and 4
52. Pearlite consists of
- (a) 6.67% C and 93.33 ferrite
 - (b) 12% Fe and 87% cementite
 - (c) 13% C and 87% ferrite
 - (d) 13% cementite and 87% ferrite

53. Addition of vanadium to steel results in improvement of
(a) heat-treatability by quenching
(b) hardenability
(c) fatigue strength
(d) resistance to oxidation at elevated temperature
54. Atomic packing factor (APF) in the case of copper crystal is
(a) 0.52 (b) 0.68
(c) 0.74 (d) 1.633
55. During peritectic solidification, one liquid
(a) combines with one solid to form a second new solid
(b) Solidifies into two different solids
(c) forms one solid
(d) forms one solid and another liquid
56. **Assertion (A):** Addition polymerization is a primary summation of individual molecules into long chains.
Reason (R): In addition polymerization, the reaction produces a small molecule as by-product.
57. **Assertion (A):** Normalized steel will have lower hardness than annealed steel.
Reason (R): The pearlite of normalized steel is finer and has lower intermolecular space.
(a) Both A and R are individually true and R is the correct explanation of A.
(b) Both A and R are individually true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.
58. Martensite is a supersaturated solution of carbon in
(a) alpha iron (b) beta iron
(c) gamma iron (d) delta iron
59. The correct sequence of creep deformation in a creep curve in order of their elongation is
(a) steady state, transient, accelerated (b) transient, steady state, accelerated
(c) transient, accelerated, steady state (d) accelerated, steady state, transient
60. Nodular grey cast iron is obtained from the grey cast iron by adding a small amount of
(a) Manganese (b) Phosphorus
(c) Magnesium (d) Chromium
61. Which one of the following pairs of axis lengths (a, b, c) and interaxial angles (α , β , γ) represents the tetragonal crystal system?
(a) $a = b = c$; $\alpha = \beta = \gamma = 90^\circ$ (b) $a = b \neq c$; $\alpha = \beta = \gamma = 90^\circ$
(c) $a \neq b \neq c$; $\alpha = \beta = \gamma = 90^\circ$ (d) $a = b = c$; $\alpha = \beta = \gamma \neq 90^\circ$
62. Consider the following quenching media:
1. Oil 2. Water
3. Water + NaOH 4. Brine
The correct sequence of these media in order of increasing hardness of steel undergoing heat treatment is
(a) 1, 3, 2, 4 (b) 2, 1, 3, 4
(c) 1, 2, 3, 4 (d) 4, 3, 2, 1

63. The alloy steel designated as 40 Cr 18 Ni 2 by Bureau of Indian Standards contains
 (a) 0.4% C, 18% Cr and 2% Ni (b) 4.0% C, 1.8% Cr and 0.2% Ni
 (c) 0.4% C, 1.8% Cr and 2% Ni (d) 0.4% C, 1.8% Cr and 0.2% Ni
64. 'Tempering' of quenched martensitic steel is necessary to improve the
 (a) hardness of the metal (b) surface texture of the metal
 (c) corrosion resistance of the metal (d) ductility of the metal
65. The molecular weight of vinyl chloride is 62.5. Thus the molecular weight of a polyvinyl chloride with a degree of polymerization of 20000 is
 (a) $\frac{20000}{62.5}$ (b) $\frac{62.5}{20000}$
 (c) 62.5×20000 (d) 20000

66. Match List-I (Name of the Element) with List-II (Crystal Structure) and select the correct answer using the codes given below the lists:

List-I

- A. Fluorspar
 B. Alpha-Iron
 C. Silver
 D. Zinc

List-II

1. Body-centered cubic
 2. Hexagonal close packed
 3. Simple cubic
 4. Face-centered cubic

Codes:

	A	B	C	D
(a)	3	2	4	1
(b)	4	1	3	2
(c)	4	2	3	1
(d)	3	1	4	2

67. Which of the following factors govern solubility of two nonferrous metals both in liquid state as well as in solid state?
 1. Crystal structure
 2. Relative size factor
 3. Chemical-affinity factor
 4. Relative valence factor

Select the correct answer using the codes given below:

- (a) 1, 2 and 3 (b) 2, 3 and 4
 (c) 1 and 4 (d) 1, 2, 3 and 4

68. Which of the following are fabricated using engineering plastics?
 1. Surface plate
 2. Gears
 3. Guide ways for machine tools
 4. Foundry patterns

Select the correct answer using the codes given below:

- (a) 1, 2 and 3 (b) 1
 (c) 2, 3 and 4 (d) 1, 2, 3 and 4

69. Consider the following statements:

Polytetrafluoroethene is

1. A thermoplastic material.
2. Having high friction coefficient.
3. A thermosetting material.
4. Having high friction coefficient.
5. An electric insulator.
6. Non sticking to surfaces.

Which of the above statements are correct?

- | | |
|----------------|----------------|
| (a) 1, 2 and 5 | (b) 2, 3 and 6 |
| (c) 3, 4 and 5 | (d) 3, 2 and 5 |

70. Which of the following fibre materials are used for reinforcement in composite materials:

1. Glass
2. Boron carbide
3. Graphite

Select the correct answer using the codes given below:

- | | |
|-------------|----------------|
| (a) 1 and 2 | (b) 1 and 3 |
| (c) 2 and 3 | (d) 1, 2 and 3 |

71. Match List-I (Phase diagram) with List-II (Characteristic) and select the correct answer using the codes given below the lists:

List-I

- A. Isomorphous system
- B. Eutectic system
- C. Peritectic system
- D. Monotectic system

List-II

1. One liquid decomposes into another liquid and solid
2. One liquid and another solid combine to form a new solid
3. Two metals are completely soluble in liquid state and completely insoluble in solid state
4. Two metals, soluble in solid and liquid state

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	4	1	2	3
(c)	2	1	4	3
(d)	4	3	2	1

72. Match List-I (Material) with List-II (Application) and select the correct answer using the codes given below the Lists:

List-I

- A. Ceramics
- B. Refractories
- C. Stones
- D. High silica glass

List-II

1. Construction of chemical plants
2. Columns and pillars
3. Lining of furnaces
4. Tiles

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	2	1	4	3
(c)	4	1	2	3
(d)	2	3	4	1

73. T.T.T. diagram indicates time and temperature transformation of
 (a) Cementite (b) Pearlite
 (c) Ferrite (d) Austenite
74. The correct composition of austenitic stainless steel used for domestic utensils is
 (a) 0.08% C, 18% Cr, 8% Ni, 2% Mn, 1% Si
 (b) 0.08% C, 24% Cr, 12% Ni, 2% Mn, 1% Si
 (c) 0.15% C, 12% Cr, 0.5% Ni, 1% Mn, 1% Si
 (d) 0.30% C, 12% Cr, 0.4% Ni, 1% Mn, 1% Si
75. Which one of the following is true?
 (a) Structure of metallic consists of atoms having valence of 5, 6 or 7
 (b) Ceramic materials have long range electron matrix bond
 (c) Polymers are composed of long chain of repeating molecules
 (d) Ceramics are weaker than metals because of weak electrostatic bond
76. In the grain-size determination using standard charts, the relation between the given size number n and the average number of grains ' N ' per square inch at a magnification of 100 X is
 (a) $N = 2^n$ (b) $N = 2^{n-1}$
 (c) $N = 2^n + 1$ (d) $N = 2^n + 1$
77. Chemicals attack atoms within grain boundaries preferentially because they have
 (a) lower energy than those in the grains
 (b) higher energy than those in the grains
 (c) higher number of atoms than in the grains
 (d) lower number of atoms than in the grains
78. As per Gibb's phase rule, if number of components is equal to 2 then the number of phases will be
 (a) ≤ 2 (b) ≤ 3
 (c) ≤ 4 (d) ≤ 5
79. **Assertion (A):** The hardness test is a slow, expensive method of assessing the mechanical properties of materials.
Reason (R): The hardness is a function of yield stress and the work hardening rate of material.
 (a) Both A and R are individually true and R is the correct explanation of A.
 (b) Both A and R are individually true but R is not the correct explanation of A.
 (c) A is true but R is false.
 (d) A is false but R is true.
80. Monel metal is an alloy of
 (a) Iron and carbon (b) Copper and zinc
 (c) Aluminium and copper (d) Copper and nickel
81. Primary object of full annealing is to
 (a) Increase toughness and yield point
 (b) Reduce ductility and resilience
 (c) Remove foreign impurities and improve surface finish
 (d) Increase ductility and machinability
82. Globular form of cementite in the structure of steel is obtained through
 (a) Normalising (b) Malleabilising
 (c) Spheroidising (d) Carbonizing

83. Gunmetal, which is used in journal bearings, contains
 (a) 88% Cu, 10% Sn, 2% Zn (b) 80% Cu, 10% Zn, 10% Al
 (c) 85% Cu, 5% Mg, 10% Al (d) 85% Cu, 5% Sn, 10% Pb
84. The correct sequence of elements of 18-4-1 HSS tool is
 (a) W, Cr, V (b) Mo, Cr, V
 (c) Cr, Ni, C (d) Cu, Zn, Sn
85. Teflon is a
 (a) Thermosetting fluorocarbon polymer
 (b) Thermoplastic fluorocarbon polymer
 (c) Inorganic compound of fluorine and carbon
 (d) Laminated phenolic material
86. In the case of rubber, vulcanization refers to the process of producing a
 (a) Linear polymer (b) Branched polymer
 (c) Cross-linked polymer (d) Network polymer
87. Polyesters can be defined as the condensation products of
 (a) Dicarboxylic acids with dihydroxy alcohols
 (b) Biphenol-A and epichloro-hydrin
 (c) Phenol and formaldehyde
 (d) Benzene and toluene
88. The coordination number for FCC crystal structure is
 (a) 4 (b) 8
 (c) 12 (d) 16
89. Match List-I (Crystal Structure) with List-II (Example) and select the correct answer using the codes given below the Lists:
- | List-I | | List-II | |
|---------------------------|--|-----------------------------------|--|
| A. Simple Cubic | | 1. Zinc | |
| B. Body-centered Cubic | | 2. Copper | |
| C. Face-centered Cubic | | 3. Alpha iron at room-temperature | |
| D. Hexagonal Close Packed | | 4. Manganese | |
- Codes:**
- | | A | B | C | D |
|-----|---|---|---|---|
| (a) | 4 | 3 | 1 | 2 |
| (b) | 4 | 3 | 2 | 1 |
| (c) | 3 | 4 | 2 | 1 |
| (d) | 3 | 4 | 1 | 2 |
90. Which one of the following pairs is not correctly matched?
 (a) Point defect in crystal lattice : Self interstitial
 (b) Linear defect in crystal lattice : Grain boundary
 (c) Planar defect in crystal lattice : External surface
 (d) Volume defect in crystal lattice : Other phases
91. A screw dislocation
 1. Lies parallel to its Burger's vector
 2. Lies perpendicular to its Burger's vector

3. Moves in a perpendicular direction to the Burger's vector
 4. Moves in an inclined direction to the Burger's vector

Select the correct answer using the codes given below:

- (a) 1 and 4
 (b) 1 and 3
 (c) 2 and 3
 (d) 2 and 4

92. According to Gibbs' phase rule, the number of degrees of freedom of an eutectic point in a binary system is

- (a) 1
 (b) 2
 (c) 0
 (d) 3

93. Assertion (A): Unlike in the case of ionic bonds, the coordination numbers for covalently bonded atoms are not controlled by the radii ratio.

Reason (R): A covalent bond has a specific direction of bonding in space.

94. Assertion (A) : The machinability of steels improves by adding sulphur to obtain so called 'Free Machining Steels'.

Reason (R) : Sulphur in steel forms manganese sulphide inclusion which helps to produce thin ribbon like continuous chip.

- (a) Both A and R are individually true and R is the correct explanation of A.
 (b) Both A and R are individually true but R is not the correct explanation of A.
 (c) A is true but R is false.
 (d) A is false but R is true.

95. Match List-I (Name of treatment) with List-II (Media used) and select the correct answer using the codes given below the lists:

List-I

- A. Pack carburizing
 B. Gas carburizing
 C. Cyaniding
 D. Nitriding

List-II

1. Ammonia gas
 2. Sodium cyanide
 3. Carburising compound
 3. Carburising compound
 4. Ethane

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	2	1	3	4
(c)	3	1	2	4
(d)	2	4	3	1

96. Consider the following pairs

Heat treatment	Effects on medium carbon steel
1. Normalising	: Grain refinement
2. Full annealing	: Uniform grain structure
3. Martempering	: Decreased ductility
4. Spheroidizing	: Maximum softness

Which of the pairs given above are correctly matched?

- (a) 1 and 2
 (b) 2 and 3
 (c) 3 and 4
 (d) 1, 2, 3 and 4

97. Match List-I (Material) with List-II (Typical use) and select the correct answer using the codes given below the Lists:

List-I

- A. Branched polyethylene
- B. Polyester
- C. Polyvinyl chloride
- D. Linear Polyethylene

List-II

- 1. Bottles
- 2. Textile fibres
- 3. Films for packaging
- 4. Transparent film

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	2	3	4	1
(c)	2	3	1	4
(d)	3	2	4	1

98. Match List-I (Steel type) with List-II (Product) and select the correct answer using the codes given below the lists:

List-I

- A. Mild steel
- B. Tool steel
- C. Medium carbon steel
- D. High carbon steel

List-II

- 1. Screws
- 2. Commercial beams
- 3. Crane hooks
- 4. Blanking dies

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	4	3
(d)	3	4	1	2

99. Match List-I (Alloy) with List-II (Application) and select the correct answer using the codes given below the lists:

List-I

- A. Silicon steel
- B. High carbon steel
- C. High speed steel
- D. Monel metal

List-II

- 1. Marine bearings
- 2. Cutting tools
- 3. Springs
- 4. Transformer laminations

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	4	3	2	1
(c)	4	2	3	1
(d)	1	3	2	4

100. Match List-I (Alloying Element) with List-II (Effect on Steel) and select the correct answer using the codes given below the lists:

List-I

- A. Vanadium
- B. Molybdenum
- C. Silicon
- D. Chromium

List-II

- 1. Increases endurance strength
- 2. Improves creep properties
- 3. Increases hardness
- 4. Increases resistance to high temperature oxidation

Codes:

(a)	2	1	3	4
(b)	1	3	2	4
(c)	2	1	4	3
(d)	1	2	4	3

101. A 60 C-plain carbon steel has, approximately,

- | | |
|---|--|
| (a) 75% of pearlite and 25% of ferrite | (b) 25% of pearlite and 75% of ferrite |
| (c) 75% of cementite and 25% of ferrite | (d) 75% of pearlite and 25% of cementite |

102. Austempering is employed to obtain

- (a) 100% martensitic structure
- (b) 100% bainitic structure
- (c) 50% martensitic and 50% bainitic structure
- (d) 100% pearlitic structure

103. Match List-I (Steel) with List-II (Application) and select the correct answer using the codes given below the Lists:

List-I

- A. Mild Steel
- B. Tool Steel
- C. High Carbon Steel
- D. Medium Carbon Steel

List-II

- 1. Ball bearing
- 2. Cold chisels
- 3. Shaft and axles
- 4. Rolled steel sections

Codes: A B C D

(a)	2	1	4	3
(b)	4	3	2	1
(c)	2	3	4	1
(d)	4	1	2	3

104. Increase of ferrite phase in steel increases

- | | |
|---------------|-----------------|
| (a) Strength | (b) Hardness |
| (c) Ductility | (d) Brittleness |

105. Consider the following statements about FCC and HCP crystal structure:

- 1. Both have same coordination number and atomic packing fraction.
- 2. Both represent closely packed crystal structures.
- 3. Both structures are generated by stacking of close packed planes on top of one another, but only the stacking sequence is different.

Which of the statements given above are correct?

- | | |
|----------------|-------------|
| (a) 1 and 2 | (b) 2 and 3 |
| (c) 1, 2 and 3 | (d) 1 and 3 |

106. The eutectoid of carbon in iron, above lower critical temperature, when cooled, results in

- | | |
|-----------------------------|--------------------------------------|
| (a) Ferrite and austenite | (b) Ferrite and cementite |
| (c) Cementite and austenite | (d) Ferrite, cementite and austenite |

107. Consider the following statements about medium carbon steel:

- 1. It can be quench-hardened but not case-hardened
- 2. It cannot be quench-hardened but case-hardening can be done
- 3. It exhibits distinct yield point under tension test

Which of the statements given above are correct?

- (a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

108. Match List-I (Alloy) with List-II (Major constituent) and select the correct answer using the codes given below the Lists:

List-I

- A. Babbitt
B. Invar
C. Gun Metal
D. Duralumin

List-II

1. Nickel
2. Tin and lead
3. Aluminium
4. Copper

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	4	3
(d)	3	4	1	2

109. Which of the following materials is used in the manufacture of extrusion nozzles?

- (a) Grey cast iron (b) Malleable cast iron
(c) White cast iron (d) Nodular cast iron

110. Consider the following statements:

1. Cast Iron has poor ability to damp vibrations.
2. Cast Iron has higher compressive strength compared to that of steel.
3. Cast Iron parts are suitable where permanent deformation is preferred over fracture.

Which of the statements given above is/are correct?

- (a) 1, 2 and 3 (b) 1 and 3
(c) 3 only (d) 2 only

111. Assertion (A) : Carburizing is done on nonferrous alloys to increase the surface hardness.

Reason (R) : Precipitation hardening of nonferrous alloys involves solution heat treatment followed by precipitation heat treatment.

112. Match List-I (Composition) with List-II (Application) and select the correct answer using the codes given below the Lists:

List-I

- A. Commercial bronze (10% Zn)
B. Red brass (15% Zn)
C. Aluminium brass (22% Zn 2% Al)
D. P-bronze (11% tin, small amount of P)

List-II

1. Radiator
2. Spring metal
3. Forging and stamping
4. Power plant and chemical equipment

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	4	3
(d)	3	4	1	2

113. Phenol formaldehyde is a/an

- (a) thermoplastic polymer (b) thermoset polymer
(c) elastomer (d) rubber

114. The pattern known as Widmanstatten structure is encountered in
 (a) tempering (b) normalizing
 (c) spheroidizing (d) annealing
115. Assertion (A) : In Addition Polymerization method, polymer is produced by adding a second monomer to the first, then a third monomer to this dimer and so on.
 Reason (R) : There must exist at least one double bond in the monomer for Addition Polymerization reaction.
- (a) Both A and R are individually true and R is the correct explanation of A.
 (b) Both A and R are individually true but R is not the correct explanation of A.
 (c) A is true but R is false.
 (d) A is false but R is true.
116. In case of power screws, what is the combination of materials used for the screw and the nut?
 (a) Cast iron screw and mild steel nut
 (b) Carbon steel screw and phosphor bronze nut
 (c) Cast iron screw and cast iron nut
 (d) Aluminium screw and alloy steel nut
117. In Zinc Blende structure each atom is surrounded by four atoms of the opposite kind which are located at the corners of which one of the following?
 (a) Tetrahedron (b) Hexahedron
 (c) Cube (d) Orthorhombic
118. Match List-I (Fe-Fe₃C Phase Diagram Characteristic) with List-II (Phase) and select the correct answer using the codes given below the Lists:

List-I

- A. Alpha (α) iron
 B. Iron carbide having crystal lattice
 C. BCC pure allotrope of iron is stable between 1388°C & its melting point at 1535°C

List-II

1. δ iron
 2. Eutectic with 3 iron and 1 carbon atom
 3. Ferrite stable below 910°C
 4. Cementite

Codes:

	A	B	C
(a)	4	2	3
(b)	3	4	1
(c)	4	2	1
(d)	3	1	2

119. Which one of the following pairs is not correctly matched?
- | Space Lattice | Atomic Radius r | Relation between and Edge Element a |
|----------------------------------|-------------------|---------------------------------------|
| (a) Simple cubic structure | : | $a^2 = 4r^2$ |
| (b) Body-centred cubic structure | : | $3a^2 = 16r^2$ |
| (c) Triclinic | : | $2a^2 = 3r^2$ |
| (d) Face-centred cubic structure | : | $a^2 = 8r^2$ |

120. What is the planar density of (100) plane in FCC (face-centred cubic) crystal with unit cell side a equal to?

(a) $\frac{1.484}{a^2}$

(b) $\frac{2}{a^2}$

(c) $\frac{1}{a^2}$

(d) $\frac{\sqrt{2}}{a^2}$

121. Match List-I (Element) with List-II (Crystal Structure) and select the correct answer using the codes given below the Lists:

List-I

- A. Alpha Iron
- B. Copper
- C. Zinc
- D. Glass

List-II

- 1. Hexagonal closed packed
- 2. Body-centred cubic
- 3. Amorphous
- 4. Face-centred cubic

Codes:

	A	B	C	D
(a)	2	3	1	4
(b)	1	4	2	3
(c)	2	4	1	3
(d)	1	3	2	4

122. Which one of the following factors is more relevant to represent complete solubility of two metals in each other?

(a) Chemical affinity

(b) Valency factor

(c) Crystal structure factor

(d) Relative size factor

123. Match List-I (Effect of Cooling) with List-II (Cooling Medium) and select the correct answer using the codes given below the lists:

List-I

- A. Martensite
- B. Very fine pearlite
- C. Fine pearlite
- D. Coarse pearlite

List-II

- 1. Water quenched
- 2. Air cooled
- 3. Furnace cooled
- 4. Oil quenched

Codes:

	A	B	C	D
(a)	1	4	2	3
(b)	2	3	1	4
(c)	2	3	4	1
(d)	1	2	3	4

124. Which one of the following is the process to refine the grains of metal after it has been distorted by hammering or cold working?

(a) Annealing

(b) Softening

(c) Recrystallizing

(d) Normalizing

125. Tempering is a process of annealing

(a) martensite at low temperatures

(b) martensite at higher temperatures

(c) bainite at low temperatures

(d) bainite at higher temperatures

126. What is the approximate strain energy expression for a dislocation of unit length, Irrespectively of its edge or screw character?

- (a) $\frac{G^2b}{2}$ (b) $\frac{Gb^2}{2}$
 (c) $\frac{G^2b}{4}$ (d) $\frac{Gb^2}{4}$

127. What is the movement of block of atoms along certain crystallographic plane and directions, termed as?

- (a) Glide (b) Twinning
 (c) Slip (d) Jog

128. Which one of the following is the correct statement?
 Pearlite in iron-carbon system is a

- (a) phase consisting of ferrite and cementite at room temperature
 (b) mechanical mixture of ferrite and cementite at room temperature
 (c) eutectic mixture of ferrite and cementite at room temperature
 (d) all the above the three are correct

129. Match List-I (Name of the invariant reaction) with List-II (Critical load reaction during cooling) and select the correct answer using the code given below the Lists:

List-I

- A. Monotectic
 B. Eutectic
 C. Eutectoid
 D. Peritectic

List-II

1. LIQUID $\rightarrow$ SOLID₁ + SOLID₂
 2. LIQUID₁ $\rightarrow$ LIQUID₂ + SOLID
 3. SOLID $\rightarrow$ SOLID₁ + SOLID₂
 4. LIQUID + SOLID₁ $\rightarrow$ SOLID₂

Codes:

	A	B	C	D
(a)	3	1	2	4
(b)	2	4	3	1
(c)	3	4	2	1
(d)	2	1	3	4

130. Which of the following factors influence hardness in a plain carbon steel ?

1. Percentage carbon
 2. Quenching media
 3. Work size

Select the correct answer using the code given below :

- (a) 1 and 2 only (b) 2 and 3 only
 (c) 1 and 3 only (d) 1, 2 and 3

131. Match List-I (Material) with List-II (Application) and select the correct answer using the code given below the lists :

List-I

- A. Fibre reinforced plastics
 B. Acrylics
 C. Phenolics
 D. Butadiene rubber

List-II

1. Automobile tyres
 2. Aircraft
 3. Lenses
 4. Electric switch cover

Codes:

	A	B	C	D
(a)	1	4	3	2
(b)	2	3	4	1
(c)	1	3	4	2
(d)	2	4	3	1

132. Which one among the following is the most effective strengthening mechanism of nonferrous metal?
- (a) Solid solution hardening (b) Strain hardening
(c) Grain size refinement (d) Precipitation hardening
133. Wood is a natural composite consisting of which of the following?
- (a) Lignin fibres in collagen matrix (b) Lignin fibres in apatite matrix
(c) Cellulose fibres in apatite matrix (d) Cellulose fibres in lignin matrix
134. Which one of the following is not a ceramic?
- (a) Alumina (b) Porcelain
(c) Whisker (d) Pyrosil
135. Which one of the following elements/alloys exhibits season cracking?
- (a) Iron (b) Brass
(c) Aluminium (d) Steel
136. Which one of the following is the correct ascending order of packing density for the given crystal structures of metals?
- (a) Simple cubic – Face central cubic – Body centred cubic
(b) Body centered cubic – Simple cubic – Face centred cubic
(c) Simple cubic – Body centred cubic – Face centred cubic
(d) Body centred cubic – Face centred cubic – Simple cubic
137. Vibration damping in machinery is best achieved by means of base structures made of which one of the following material?
- (a) Low carbon steel (b) Nodular iron
(c) Grey cast iron (d) White cast iron
138. For a Rhombohedral space lattice, which one of the following is correct ?
- (a) $\alpha = \beta = \gamma = 90^\circ$ (b) $\alpha = \beta = \gamma \neq 90^\circ$
(c) $\alpha = \gamma = 90^\circ \neq \beta$ (d) $\alpha \neq \beta \neq \gamma \neq 90^\circ$
139. Match List-I (Component) with List-II (Required Property) and select the correct answer using the code given below the lists :
- | List-I | List-II |
|--------------------------|--|
| A. Blades of bulldozer | 1. High wear resistance and high toughness |
| B. Gas turbine blades | 2. Low Young's modulus and high fatigue strength |
| C. Drill bit | 3. High wear and abrasion resistance |
| D. Spring of automobiles | 4. High creep strength and good corrosion resistance |

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	1	4	3	2
(c)	3	4	1	2
(d)	1	2	3	4

140. Structure of a polymer is:

- (a) Long chain (b) Rhombic
(c) Cubic (d) Closed pack hexagonal

141. In the atomic hard-sphere model of the crystal structure of Copper, what is the edge length of unit cell?

- (a) $2 \times \text{Atomic radius}$ (b) $(4/\sqrt{3}) \times \text{Atomic radius}$
(c) $(2/\sqrt{2}) \times \text{Atomic radius}$ (d) $\sqrt{2} \times \text{Atomic radius}$

142. Which one of the following is correct?

When "devitrification" of inorganic glasses done,

- (a) glass transforms from crystalline to noncrystalline
(b) glass transforms into a fully transparent material
(c) glass transforms from monocrystalline state to polycrystalline state
(d) glass is relieved of internal stresses

143. What is a surface imperfection, which separates crystals of different orientations a polycrystalline aggregate, called?

- (a) Edge dislocation (b) Stacking fault
(c) Grain boundary (d) Screw dislocation

144. Which one of the following statements is correct in the case of screw dislocations?

($\vec{b}$ = Burger's Vector; $\vec{t}$ = Imaginary Vector)

- (a) $\vec{b}$ is perpendicular to $\vec{t}$ (b) $\vec{b}$ is parallel to $\vec{t}$
(c) $\vec{b}$ is inclined to $\vec{t}$ (d) $\vec{b}$ and $\vec{t}$ are non-coplanar and non-intersecting

145. Which one of the following is correct?

Malleability is the property by which a metal or alloy can be plastically deformed by applying?

- (a) tensile stress (b) bending stress
(c) shear stress (d) compressive stress

146. Which of the following elements given below determine(s) the maximum attainable, hardness in steel?

1. Chromium
2. Manganese
3. Carbon
4. Molybdenum

Select the correct answer using the code given below:

- (a) 1 only (b) 1 and 2
(c) 3 only (d) 2 and 4

147. Coefficient of Expansion is practically nil in a particular alloy. What is this alloy?
- (a) Hadfield Manganese Steel (b) Invar
(c) Vitallium (d) Stellite
148. Consider the following statements relating to mechanical properties of ceramics:
1. Tensile strength is theoretically high but is practice quite low.
 2. Compressive strength is many times lower than tensile strength.
 3. Shear strength is high.
 4. Transverse strength is easy to ascertain.
- Which of the statements given above are correct?
- (a) 1 and 3 (b) 1 and 4
(c) 2 and 3 (d) 2 and 4
149. Consider the following statements in respect of austenitic stainless steels:
1. Austenitic stainless steels are hardened and strengthened by cold working.
 2. Austenitic stainless steels cannot be quenched and tempered.
- Which of the statements given above is/are correct?
- (a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2
150. **Assertion (A):** Lever Rule can be applied to determine relative amounts of phases present at any temperature.
Reason (R): Lever Rule is restricted to estimate relative phases, only if they are solid phases.
151. **Assertion (A):** Elements are classified into metals and nonmetals on the basis of their atomic weights.
Reason (R): The valence electron structures contribute to the primary bonding between the atoms to form aggregates.
152. Which one of the following is correct?
Babbitts are used for
- (a) gears (b) bearings
(c) bolts (d) clutch liners
153. What is the process by which two or more chemically different monomers are polymerized to form a cross link polymer together with a by-product such as water or ammonia, known as?
- (a) Addition polymerization (b) Co-polymerization
(c) Linear polymerization (d) Condensation polymerization
154. Which material is used for bushes in the bushed-pin type of flexible coupling?
- (a) Gun metal (b) Plastic
(c) Rubber (d) Aluminium
155. Which one of the following crystal systems is valid for gold ?
- (a) Orthogonal (b) Cubic
(c) Hexagonal (d) Triclinic
156. Which one of the following is correct for 'Climb' ?
- (a) Dislocation moves parallel to the slip plane
(b) Dislocation moves perpendicular to the slip plane
(c) Sliding of one plane of atoms over the other plane
(d) Dislocation moves from a slip plane to another slip plane

157. Which one of the following is correct for "Burger's vector" in screw dislocation ?
(a) Perpendicular to the dislocation line (b) Inclined to the dislocation line
(c) Parallel to the dislocation line (d) Opposite to the dislocation line
158. Which one of the following defects is 'Schottky defect' ?
(a) Vacancy defect (b) Compositional defect
(c) Interstitial defect (d) Surface defect
159. Which one of the following elements is an austenitic stabilizer ?
(a) Chromium (b) Tungsten
(c) Nickel (d) Molybdenum
160. Which one of the following elements is a ferritic stabilizer ?
(a) Nickel (b) Manganese
(c) Copper (d) Chromium
161. The elements which, added to steel, help in chip formation during machining are
(a) sulphur, lead and phosphorous (b) sulphur, lead and cobalt
(c) aluminium, lead and copper (d) aluminium, titanium and copper
162. Which one of the following cast irons consists of carbon in rosette form ?
(a) White cast iron (b) Gray cast iron
(c) Malleable cast iron (d) Nodular cast iron
163. Which one of the following possesses the property of nonsparking character ?
(a) Hadfield's manganese steel (b) Spring steel
(c) Stellite (d) Invar
164. Nano composite materials are highly preferable in design consideration for their
(a) high resistance to crack propagation (b) vibration resistance
(c) impact resistance (d) high resilience
165. Which one of the following mediums is used for the fastest cooling rate of steel quenching ?
(a) Air (b) Oil
(c) Water (d) Brine
166. Which one of the following materials is not a composite ?
(a) Wood (b) Concrete
(c) Plywood (d) Sialon
167. Which of the following composites are 'dispersion-strengthened composites' ?
(a) Particulate composites (b) Laminar composites
(c) Fiber reinforced composites (d) Short-fiber discontinuous composites
168. Why are Babbitt alloys used for bearing material ?
(a) They have excellent embeddability
(b) They are relatively stronger than other bearing materials
(c) They do not lose strength with increase in temperature
(d) They have high fatigue strength
169. Which one of the following materials can be subjected to an age hardening process ?
(a) HSS (b) Aluminium
(c) Pure iron (d) Stellite

OOOO

ANSWERS

MATERIAL SCIENCE

- | | | | | | | |
|----------|----------|----------|----------|----------|------------|------------|
| 1. (d) | 2. (b) | 3. (a) | 4. (b) | 5. (a) | 6. (b) | 7. (d) |
| 8. (c) | 9. (b) | 10. (b) | 11. (a) | 12. (c) | 13. (b) | 14. (c) |
| 15. (b) | 16. (d) | 17. (c) | 18. (c) | 19. (d) | 20. (d) | 21. (b) |
| 22. (c) | 23. (c) | 24. (c) | 25. (a) | 26. (b) | 27. (b) | 28. (d) |
| 29. (b) | 30. (b) | 31. (a) | 32. (c) | 33. (a) | 34. (c) | 35. (b) |
| 36. (c) | 37. (a) | 38. (c) | 39. (c) | 40. (d) | 41. (a, c) | 42. (b, c) |
| 43. (d) | 44. (b) | 45. (d) | 46. (d) | 47. (b) | 48. (d) | 49. (a) |
| 50. (d) | 51. (b) | 52. (d) | 53. (b) | 54. (c) | 55. (a) | 56. (c) |
| 57. (d) | 58. (a) | 59. (b) | 60. (c) | 61. (b) | 62. (c) | 63. (a) |
| 64. (d) | 65. (c) | 66. (d) | 67. (d) | 68. (c) | 69. (a) | 70. (d) |
| 71. (d) | 72. (d) | 73. (d) | 74. (a) | 75. (c) | 76. (b) | 77. (b) |
| 78. (c) | 79. (b) | 80. (d) | 81. (d) | 82. (c) | 83. (a) | 84. (a) |
| 85. (b) | 86. (c) | 87. (a) | 88. (c) | 89. (b) | 90. (b) | 91. (b) |
| 92. (c) | 93. (c) | 94. (a) | 95. (a) | 96. (d) | 97. (a) | 98. (d) |
| 99. (c) | 100. (d) | 101. (a) | 102. (b) | 103. (d) | 104. (a) | 105. (d) |
| 106. (b) | 107. (c) | 108. (c) | 109. (c) | 110. (d) | 111. (d) | 112. (b) |
| 113. (b) | 114. (a) | 115. (a) | 116. (b) | 117. (a) | 118. (b) | 119. (c) |
| 120. (b) | 121. (c) | 122. (c) | 123. (a) | 124. (c) | 125. (a) | 126. (b) |
| 127. (c) | 128. (b) | 129. (d) | 130. (a) | 131. (b) | 132. (d) | 133. (d) |
| 134. (d) | 135. (b) | 136. (c) | 137. (c) | 138. (b) | 139. (c) | 140. (a) |
| 141. (c) | 142. (c) | 143. (c) | 144. (b) | 145. (d) | 146. (d) | 147. (b) |
| 148. (a) | 149. (c) | 150. (c) | 151. (d) | 152. (b) | 153. (d) | 154. (c) |
| 155. (b) | 156. (b) | 157. (c) | 158. (a) | 159. (c) | 160. (d) | 161. (a) |
| 162. (d) | 163. (b) | 164. (b) | 165. (d) | 166. (d) | 167. (a) | 168. (a) |
| 169. (b) | | | | | | |

Casting

Casting is the oldest and still most widely used process. A mould cavity is created out of sand or some permanent material and liquid metal is poured into this cavity. The product is taken out after solidification. If the mould or pattern is broken after each cast then it is called expendable mould/pattern. If the same mould/pattern is used for a number of castings, it is called reusable mould/pattern. Pattern is the replica of the part being produced from the pouring temperature of the liquid metal to the room temperature, the material undergoes following shrinkages :

1. Liquid from the pouring temperature to the liquid at the melting point.
2. Shrinkage during the phase change.
3. Solid at the melting point to solid at the room temperature.

First two stages shrinkages are compensated by providing a riser. The riser design should be such that it solidifies after casting so that liquid metal is available to compensate liquid shrinkage. Third stage of shrinkage is compensated by providing allowance on the pattern. Following are the allowances that are provided on the pattern :

1. Shrinkage allowance : to compensate the third stage of shrinkage.
2. Machining allowance: casting produces poor finish and tolerances. So some margin is given to the pattern for machine to produce after solidification.
3. Draft allowance: around $1/2^\circ$ to 2° taper is provided over the pattern for easy removal from the sand mould. Otherwise straight pattern may destroy the shape of product during the removal.

It should be noted here that while casting gray cast iron due to the appearance of graphite (low density material) the casting expands upon solidification. The percentage volume change can be expressed as

$$\% V = 2 \times (\% \text{ graphite} - 2.8)$$

So negative shrinkage allowances are given to the pattern while casting gray cast iron. Generally the shrinkage is expressed in linear units. In certain cases like large flat plates or domes, distortion allowances are given to the pattern. The commonly used patterns are as follows :

1. **Loose patterns** : These are the single piece pattern but incorporating the allowances, generally these patterns are made up of wood. Gating system is cut from sand manually.
2. **Gated patterns** : The gating system and runner is the integral part of the pattern. This would eliminate the hand cutting of the runners and gates and hence improved productivity.
3. **Match plate pattern** : The cope and drag portions of the pattern are mounted on the opposite side of wood or metal plate contouring to the parting line.

4. **Cope and drag patterns** : The cope and drag halves at the mould are made separately but it requires accurate alignment by guide and locating pins. These types of patterns are used for castings which are heavy and inconvenient for handling as also for continuous production.

3.1 DESIGN OF RISERS

As discussed before the purpose of riser is to provide liquid metal to compensate liquid and shrinkage during phase change, the secondary purpose of riser is to show that whether casting is full or not. So the riser design should be such that it solidify after casting, so that liquid metal is available to compensate shrinkage. The solidification time for both riser and casting can be expressed as :

$$t \propto \left(\frac{V}{A} \right)^2 \quad \checkmark$$

where v is the volume of riser and A is surface area of riser.

Riser should be designed in such a way that it has minimum surface area to begin the design, the riser volume can be taken as three times the liquid shrinkage but this design has to be checked whether riser will solidify before or after casting. The design of risers can be understood by taking following examples.

Example : 3.1

Compare the solidification time of two optimum side riser having same volume, one is cylindrical and other is square paretlopipe.

Solution :

The riser which is placed on the top of casting and one surface which comes in contact with the metal is called top riser. The riser which is placed on the sides both top and bottom faces are exposed to atmosphere is called side riser. In the riser design the area of riser which is exposed to atmosphere is considered.

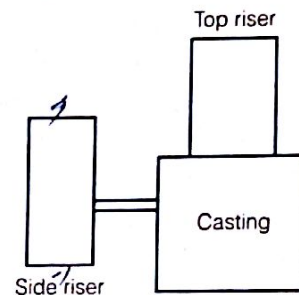


Fig. 3.1

Cylindrical rise :

volume of riser

$$V = \pi r^2 h \quad \checkmark$$

area of riser

$$A = 2\pi r^2 + 2\pi rh$$

for minimum surface area of riser

$$A = 2\pi r^2 + 2\pi r \left(\frac{V}{\pi r^2} \right)$$

$$A = 2\pi r^2 + \frac{2V}{r}$$

$$\frac{dA}{dr} = 4\pi r - \frac{2V}{r^2} = 0$$

$$r = \left(\frac{V}{2\pi} \right)^{1/3}$$

So

$$\left(\frac{V}{A} \right) = \frac{\pi r^2 h}{2\pi r^2 + 2\pi rh} \quad \text{---(1)}$$

$$\dots(2)$$

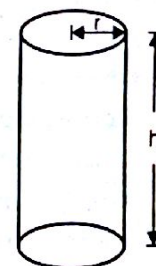


Fig. 3.2

Putting this value in equation (1) we get

$$h = 2r$$

So

$$\left(\frac{V}{A}\right)_{\text{cylinder}} = \frac{2\pi r^3}{6\pi r^2} = \frac{r}{3} \quad \dots(3)$$

Square Parallelepiped:

$$\text{Volume} = a^2 h_1 = v \quad \dots(4)$$

$$\text{Area (A)} = 2a^2 + 4ah_1 \quad \dots(5)$$

or

$$A = 2a^2 + 4a\left(\frac{v}{a^2}\right)$$

$$A = 2a^2 + \frac{4v}{a}$$

for minimum surface area $\frac{dA}{da} = 4a - \frac{4v}{a^2} = 0$

$$a = (v)^{1/3}$$

Putting this value in equation (4) we get

$$h_1 = (v)^{1/3} = a \quad \dots(6)$$

$$\left(\frac{V}{A}\right)_{\text{square}} = \frac{a^3}{6a^2} = \frac{a}{6}$$

from equation (3) and (7)

$$\frac{t_{\text{cylinder}}}{t_{\text{square}}} = \frac{\left(\frac{V}{A}\right)_{\text{cylinder}}}{\left(\frac{V}{A}\right)_{\text{square}}} = \frac{\left(\frac{r}{3}\right)^2}{\left(\frac{a}{6}\right)^2} = 4\left(\frac{r}{a}\right)^2 \quad \dots(8)$$

If the volume at both the risers are equal these

$$2\pi r^3 = a^3 \quad h = 2r$$

so

$$\frac{r}{a} = \left(\frac{1}{2\pi}\right)^{1/3}$$

Putting this value in equation (8) we get

$$\frac{t_{\text{cylinder}}}{t_{\text{square}}} = 4\left(\frac{1}{2\pi}\right)^{2/3} = 1.17$$

Example : 3.2

Determine the dimensions of a cylindrical side and top riser used for casting brass cube of 20 cm dimension. The volume shrinkage can be taken as 9%.

Solution :

Side Riser : For optimum side riser $h = 2r$ where h is the height and r is the radius. Initially let us take top riser volume to be 3 times the shrinkage.

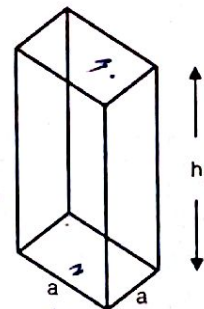


Fig. 3.3

$$\frac{a^3}{4a^2} = \frac{9}{4} \quad \dots(7)$$

for eq. (8) (11)

$$V_r = 3 \times 0.09 \times (20)^3 \text{ cm}^3 = \pi r^2 h$$

since

$$\frac{r}{h} = \frac{7 \text{ cm}}{14 \text{ cm}}$$

Confirming these dimensions of riser

$$\left(\frac{V}{A}\right)_{\text{riser}} = \frac{\pi r^2 h}{2\pi r^2 + 2\pi r h} = \frac{2\pi r^3}{6\pi r^2} = \frac{r}{3}$$

$$\left(\frac{V}{A}\right)_{\text{riser}} = 2.33$$

$$\left(\frac{V}{A}\right)_{\text{casting}} = \frac{(20)^3}{6 \times (20)^2} = 3.33$$

So

$$\left(\frac{V}{A}\right)_{\text{casting}} > \left(\frac{V}{A}\right)_{\text{riser}}$$

So riser will solidify prior to casting, so these dimensions are not correct since at least riser should solidify along with casting. So

$$\left(\frac{V}{A}\right)_{\text{riser}} \geq \left(\frac{V}{A}\right)_{\text{casting}}$$

So

$$\frac{r}{3} \geq 3.33 = r \geq 9.99 \text{ cm} \approx 10 \text{ cm}$$

($\because h = 2r$)

$$h \geq 20 \text{ cm}$$

Top riser :

$$V = \pi r^2 h$$

$$A = \pi r^2 + 2\pi r h$$

The bottom area of riser coming in contact with casting will not be considered in the design analysis because there is no heat transfer through that area

So

$$A = \pi r^2 + 2\pi r \left(\frac{V}{\pi r^2}\right)$$

$$A = \pi r^2 + \frac{2V}{r}$$

for minimum area of riser

$$\frac{dA}{dr} = 2\pi r - \frac{2V}{r^2} = 0$$

So

$$r = \left(\frac{V}{\pi}\right)^{1/3}$$

$$h = \left(\frac{V}{\pi}\right)^{1/3} = r$$

$$\left(\frac{V}{A}\right)_{\text{riser}} = \frac{\pi r^2 h}{2\pi r h + \pi r^2} = \frac{\pi r^3}{3\pi r^2} = \frac{r}{3}$$

$$V_r = 2160 \text{ cm}^3 = \pi r^2 h$$

$$r = h = 8.82 \text{ cm}$$

$$\left(\frac{V}{A}\right)_{\text{riser}} = 2.94$$

$$\left(\frac{V}{A}\right)_{\text{casting}} = \frac{(20)^3}{5 \times 20 \times 20} = 4$$

So again this riser dimension is not correct and therefore optimum riser dimension for top riser is

$$\frac{r}{3} \geq 4$$

$$r = h = 12 \text{ cm.}$$

So

3.2 RISER DESIGN FOR STEEL CASTINGS

Steels are difficult to cast because it undergoes large amount of shrinkage during solidification. It also has tendency to absorb atmospheric oxygen. So Silicon is added in the material to remove the trapped oxygen. The sound castings particularly in case of steel can be obtained by either using insulating pad or exothermic materials. As shown in figure 3.4.

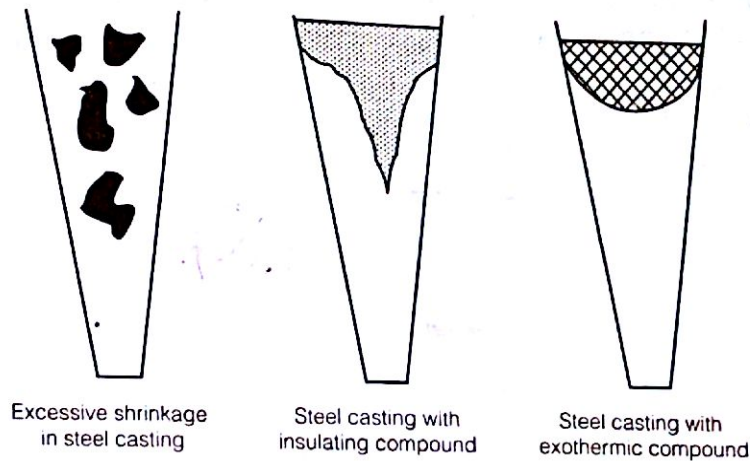


Fig. 3.4 : Steel Casting

When insulating material is kept at the top, the heat transfer decreases and hence the extent of shrinkage at the centre line decreases. But when exothermic compounds are kept at the top of riser, the centre line shrinkage can be completely eliminated. Caine curves are used to calculate the size of riser shown in figure 3.5.

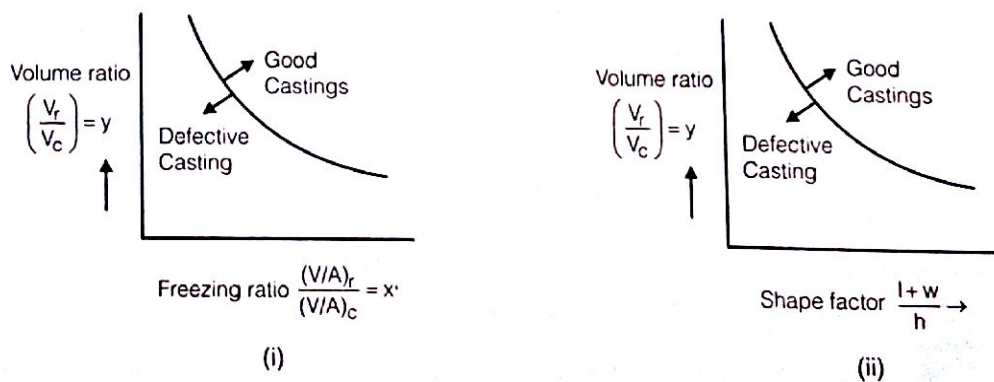


Fig. 3.5 : Caine Curve

The x-axis is freezing ratio $\frac{\left(\frac{V}{A}\right)_{\text{riser}}}{\left(\frac{V}{A}\right)_{\text{casting}}}$ and y-axis is volume ratio of riser to casting. The equations of their Caine curve is

$$X = \frac{a}{y-b} + c$$

where a is freezing constant, b is contraction ratio and c depends upon the medium around the riser. For steel the value of a = 0.1 and b = 0.03.

Example : 3.3

Chvorinov and Caine gave rules for solidification time and freezing ratio for a riser. Using these rules or otherwise find the size of a cylindrical riser of height to diameter ratio as one for a steel casting of size $250 \times 250 \times 50 \text{ mm}^3$, when the casting is fed horizontally and riser is a side one. Thickness of the casting is 50 mm. For steel a = 0.10, b = 0.03 and c = 1.00. Consider it as a long bar of cross-section 250×50 .

Solution :

Cylindrical Side riser :

It was proved before that for optimum side riser

$$h = d$$

The parameter's of Caine's curve

Side or Top ?

$$X = \frac{\left(\frac{V}{A}\right)_{\text{riser}}}{\left(\frac{V}{A}\right)_{\text{casting}}} = \frac{\frac{\pi}{4} d^2 h}{\frac{\pi}{4} d^2 \times 2 + \pi d h} = \frac{\frac{\pi}{4} d^2 h}{\frac{250 \times 250 \times 50}{2 \times (250 \times 50) + 2 \times (250 \times 250) + 2 \times (50 \times 250)}}$$

$$X = \frac{\frac{\pi}{4} d^3}{\frac{3\pi}{2} d^2} = \frac{d}{17.8}$$

$$X = \frac{d}{17.8}$$

$$X = \frac{d}{107.1}$$

$$Y = \frac{V_r}{V_c} = \frac{\frac{\pi}{4} d^3}{250 \times 250 \times 50} = \frac{d^3}{3.9788 \times 10^6}$$

Putting there values is caines equals

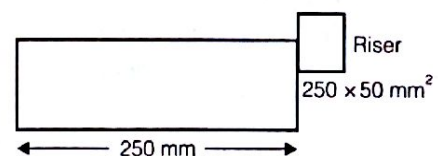


Fig. 3.6

$$\frac{d}{107.1} = \frac{0.1}{\frac{d^3}{3.9788 \times 10^6} - 0.03} + 1$$

$$\frac{d}{107.1} \left(\frac{d^3}{3.9788 \times 10^6} - 0.03 \right) = \frac{d^3}{3.9788 \times 10^6} + 0.07$$

$$d = 128.4 \text{ mm}$$

3.3 GATING SYSTEM ✓

It refers to all the elements which are used to push the liquid metal into mould cavity. The detailed process is shown in the figure 3.7. Initially the liquid metal is poured into a pouring basin to settle the turbulence of liquid metal and almost with laminar flow liquid enters into the sprue. In the sprue there is a ceramic filter primarily to remove dross (lighter impurities) and also some larger impurities. A ceramic splash core is placed at the bottom of the sprue to avoid the erosion of sand in the mould. Compensation for vena contracta is provided at a place where liquid metal just enters into the horizontal runner otherwise vacuum will be formed in the gating system and atmosphere gases will be dissolved in the liquid metal. Skim bob is placed in the horizontal runner just before liquid metal enters into the mould cavity, so that heavier impurities settle down and lighter impurities float over it and almost pure metal enters into the mould cavity. The cross-section of horizontal runner increases in the forward direction to maintain uniform pressure (atmospheric) in the gating system.

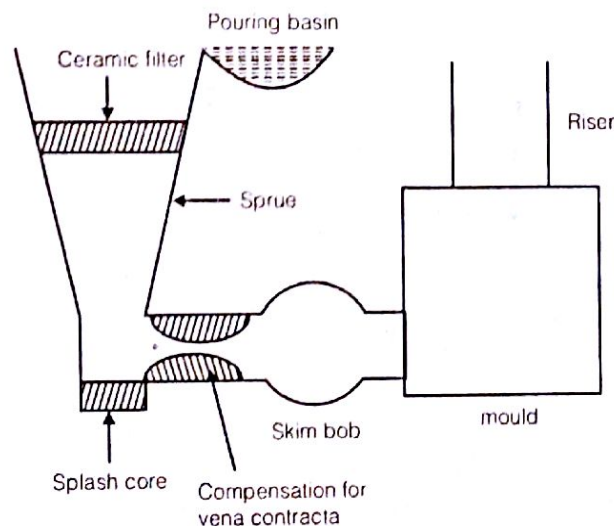


Fig. 3.7 : Gating System

There are 3 types of gates namely top gating, bottom gating and horizontal gating. In top gating the mould cavity can be filled in minimum time but there will be turbulence in the liquid metal which erodes the sand. This sand mixed with the liquid metal and after reaction it produces FeSiO_3 (faylite) which is very hard. These micro faylite products will be distributed throughout the material and when it comes in contact with the cutting tool, there will be sudden increase in the cutting forces and tool will be eroded gradually. In the bottom gating system the flow will be laminar but it will take more time to fill the casting and it is not favourable situation for the alloys

having larger mushy zone, so top gates are used in case of large castings or for the alloys having larger mushy zone.

1. Top Gate : ✓

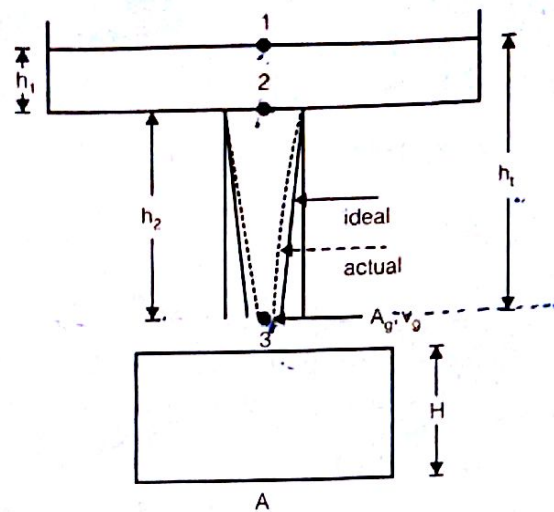


Fig. 3.8 : Design of Sprue

A_g is the cross-section area and v_g is the velocity of liquid metal coming out of the gate. (1, 3) $v_1 = 0$ Neglected

$$v_g = \sqrt{2gh_1}$$

A and H are the cross-section area and height of mould cavity. t_f is the total time to fill the mould by top gate then. $p_1 = p_3$ atmospheric pressure

$$A_g v_g t_f = AH$$

$$t_f = \frac{AH}{A_g \sqrt{2gh_1}} \quad \dots(1)$$

Upon applying Bernoulli's equation between 2 and 3 we get,

$$\frac{p_2}{\rho g} + \frac{v_2^2}{2g} + h_2 = \frac{p_3}{\rho g} + \frac{v_3^2}{2g} \quad \dots(2)$$

Point 3 is open to atmosphere and if the cross-section area of the sprue is same then by continuity equation we can write

$$v_2 = v_3 \quad \text{as } p_3(\text{gauge}) = 0$$

So equation (2) reduces to $\frac{p_2}{\rho g} + h_2 = 0$

$$\frac{p_2}{\rho g} = -h_2$$

It means that at point (2) in the sprue there will be vacuum and it will capture atmosphere into liquid metal through sand voids. This will produce blow holes in the casted part. This phenomenon is called aspiration effect which is not desirable. So to avoid this phenomenon the cross-section area of the sprue is changed to have uniform atmospheric pressure throughout the sprue. Let us again take equation (2) if the pressure throughout sprue is uniform

$$\frac{v_2^2}{2g} + h_2 = \frac{v_3^2}{2g} \quad \dots(3)$$

Also

$$\begin{aligned} A_2 v_2 &= A_3 v_3 \\ v_2 &= \frac{A_3}{A_2} v_3 = R v_3 \end{aligned}$$

Where R is area ratio $\left(R = \frac{A_3}{A_2} \right)$

Putting this value in equation (3) we get,

$$R^2 \frac{v_3^2}{2g} + h_2 = \frac{v_3^2}{2g}$$

$$(1 - R^2) \frac{v_3^2}{2g} = h_2$$

But

$$v_3^2 = 2gh_1$$

So

$$1 - R^2 = \frac{h_2}{h_1}$$

$\Rightarrow$

$$R^2 = 1 - \frac{h_2}{h_1} = \frac{h_1}{h_t}$$

$$R = \sqrt{\frac{h_1}{h_t}}$$

This should be the area ratio in the sprue to avoid aspiration effect. According to this expression the cross section area should decrease linearly but ideally it should be a curve as shown in figure because friction loss in the sprue has to be incorporated. Also this curve avoids boundary layer separation.

2. Bottom Gate :

By applying Bernoulli's equation between (1) and (2) we get

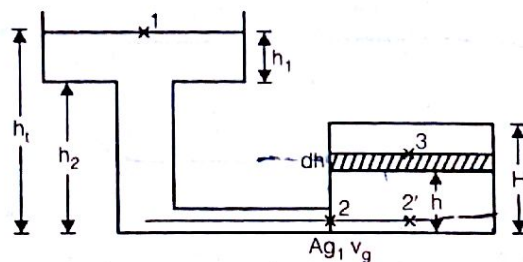


Fig. 3.9 : Bottom Gate

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + h_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + 0 \quad \dots(3)$$

v_1 can be neglected because pouring basin area is very large and p_1 is atmospheric pressure. So equation (3) reduces to

$$h_t = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} \quad \dots(4)$$

Since pressure on the 2-2' plane will remain same, so by applying Bernoulli's equation between this point and (3) we get

$$\frac{p_2}{\rho g} = \frac{p_3}{\rho g} + h \quad (\text{but } p_3 \text{ is atmospheric pressure and cross-section area of casting is same so } v_2 = v_3)$$

$$\text{So} \quad \frac{p_2}{\rho g} = h \quad \dots(5)$$

putting it in equation (4) we get

$$\begin{aligned} \frac{v_2^2}{2g} &= h_t - h \\ v_2 &= \sqrt{2g(h_t - h)} = v_g \quad \checkmark \end{aligned} \quad \dots(6)$$

Let us consider that in dt_t time the liquid metal comes out of gate increases the level of metal in the cavity by dh . Equating the volume we get

$$\begin{aligned} A_g v_g dt_t &= A dh \\ dt_t &= \frac{A}{A_g \sqrt{2g(h_t - h)}} dh \end{aligned}$$

To calculate total time integrate this exposing from 0 to H.

$$\begin{aligned} t_t &= \int_0^H \frac{A}{A_g \sqrt{2g(h_t - h)}} dh = \frac{A}{A_g \sqrt{2g}} \int_0^H \frac{dh}{\sqrt{h_t - h}} \\ &= \frac{A}{A_g \sqrt{2g}} \left[\frac{(h_t - h)^{-\frac{1}{2}+1}}{-\frac{1}{2}+1} (-1) \right]_0^H \\ &= \frac{A}{A_g \sqrt{2g}} \times 2 \left[\sqrt{h_t - H} - \sqrt{h_t} \right] \end{aligned}$$

$$t_t = \frac{2A}{A_g \sqrt{2g}} \left[\sqrt{h_t} - \sqrt{h_t - H} \right]$$

Example : 3.4

A casting of size 100 cm × 100 cm × 25 cm was filled by top and bottom gates with manometric height in pouring basin to be 25 cm. Compare the time to fill the casting by different gates. The area of gate is 5 cm².

Solution.

$$\begin{aligned} \text{Casting area } A &= 100 \times 100 = 10^4 \text{ cm}^2 \\ \text{casting height } H &= 25 \text{ cm} \\ \text{manometric height } h_t &= 25 \text{ cm} \\ \text{Gate area } A_g &= 5 \text{ cm}^2 \end{aligned}$$

Top Gate :

$$t_{t_1} = \frac{AH}{A_g \sqrt{2gh_1}} = \frac{10^4 \times 25}{5 \times \sqrt{2 \times 981 \times 25}} = 225.7 \text{ s}$$

Bottom Gate :

$$t_{t_2} = \frac{2 \times 10^4}{5 \times \sqrt{2 \times 981}} [\sqrt{25} - \sqrt{25 - 25}] = 451.5 \text{ s}$$

It can be noted down that $t_{t_2} = 2t_{t_1}$. This will be the case when manometric height is equal to the height of casting but in all the cases $t_{t_2} > t_{t_1}$.

Example : 3.5

In the below example determine the total time required to fill the entire casting and riser.

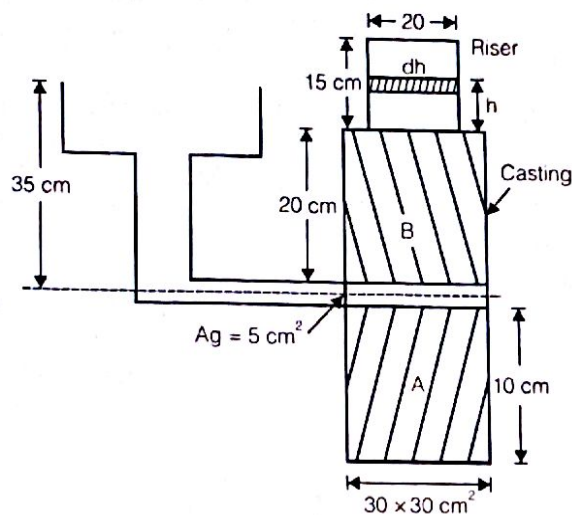


Fig. 3.10

Solution :

It is the horizontal gate. Section A of the mould will be filled like top gate

So
$$t_{t_1} = \frac{(30)^2 \times 10}{5 \times \sqrt{2 \times 981 \times 35}} = 6.86 \text{ seconds}$$

section B of the mould will be filled like bottom gate.

So
$$t_{t_2} = \frac{(30)^2 \times 20}{5 \times \sqrt{2 \times 981}} [\sqrt{35} - \sqrt{35 - 20}] = 16.60 \text{ s}$$

Riser will be filled like bottom gate

$$t_{t_3} = \int_{20}^{35} \frac{\frac{\pi}{4} (20)^2}{5} \frac{dh}{\sqrt{2g(35-h)}}$$

$$\begin{aligned}
 t_3 &= \frac{-2 \times \frac{\pi}{4} (20)^2}{5\sqrt{2 \times 981}} \left[\sqrt{h_1 - H} \right]_{20}^{35} \\
 &= -2.83 [\sqrt{35 - 35} - \sqrt{35 - 20}] \\
 &= 2.83 \times \sqrt{35 - 20} \\
 t_3 &= 10.98 \text{ s}
 \end{aligned}$$

Total time to full the casting

$$t_1 + t_2 + t_3 = 16.60 + 10.98 + 6.86 = 34.4 \text{ s}$$

3.4 GREEN SAND MOULD

Majority of castings are being produced by sand moulds. Green sand indicates freshly prepared mould or the mould in which there is some moisture. The composition of green sand mould is 70-85% sand, 10-20% clay, 3-6% water and 1-6% additives like cereals, asphalt sea coal etc. Clay is a principal source of strength and plasticity of moulding sand. It is a binder of moulding sand. Following are the properties of mould.

- ✓ 1. **Green Strength** : After mixing with water the sand must have adequate strength for handling.
- ✓ 2. **Dry Strength** : When the liquid metal is poured, moisture immediately vapourizes. The dry mould must have strength to resist erosion.
- ✓ 3. **Permeability** : Gases are formed due to mould metal reaction and also due to vapourization. The mould must be porous to permit the gases to pass off, otherwise casting will have gas holes defect. If the grain size of sand is large, there will be larger void size between particles. This leads to larger permeability.

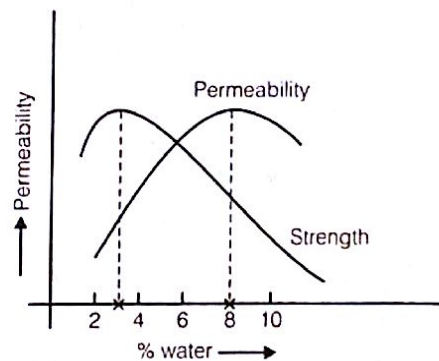


Fig. 3.11 : Permeability and strength Vs moisture content

As shown in figure 3.11 if the water content is less, these voids will be filled with smaller sand particles which results in lower permeability. By increasing the water content, smaller sand particles are also combine together, this increase permeability. Once the percentage of water goes beyond 8%, water start accumulating in these voids and the sand becomes pasty. This decreases permeability and decrease in strength of the mould. Permeability is quantified by Permeability Number (PN) which is defined as

$$PN = \frac{VH}{PAT}$$

PN is the ratio in millimeters at which air will pass through the sand under a standard condition of pressure.

Where

V = volume of air passed through standard cylindrical specimen = 2000 cc

H = height of sand specimen = 5.08 cm

P = Pressure difference across specimen 10 g/cm²

A = Cross section area of specimen = 20.26 cm²

T = Time in second for 2000 cc air to pass through specimens

$$\text{So, } PN = \frac{3007.2}{T}$$

4. **Thermal stability** : Heat of the liquid metal may cause rapid expansion and mould surface may crack and destroy its shape.
- ✓ 5. **Refractoriness** : This is the property due to which sand remains solid by increasing the temperature.
6. **Collapsibility** : During the solid contraction of the cast part if mould creates resistance, cracks will appear over it. So the property of sand mould due to which it does not create resistance of the contracting metal is called collapsibility. The additives like cereals, wood flour etc burns and hence creates extra space for the contraction of solid.
7. **Flowability** : It is the ability of sand to flow upon ramming
8. **Loam sand** : As discussed earlier that gray C.I. upon solidification expands, so green sand will have very poor collapsibility. To cast these materials loam sands are used. It is a mixture of sand, silt, clay and excess amount of water. It is 50% sand and 50% silt and clay.

3.5 TYPES OF SOLIDIFICATION

3.5.1 Skin forming

This type of solidification take place either in pure materials or the alloys having eutectic composition. Mould boundaries will be at the room temperature and when the liquid metal comes in contact with walls, solid will first appear in the wall region. The solidification front will move towards centre and solidification will appear layer by layer.

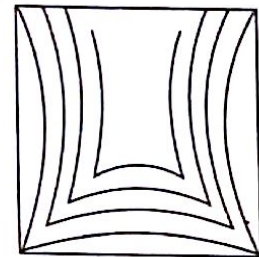


Fig. 3.12 : Skin Forming

3.5.2 Dendritic Growth

If mushy zone appear during the solidification of alloy (which will be there in most of the cases), it results in this type of solidification. Initially a solid will nucleate near the boundary and solidification front will move towards the centre. Solid will also nucleate somewhere in the liquid region and it moves both towards centre and towards the primary dendrite. So in this case the solidification is not uni-directional, the place where primary and secondary dendrites meet there will be micro voids which cannot be compensated by riser. As a result of that, casting will be defective.

To provide uni-directional solidification chills are used in such cases. Chills are made of the same material and are kept all

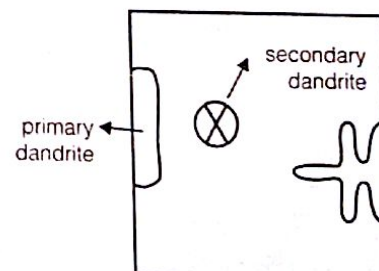


Fig. 3.13 : Dendritic Growth

around the mould. When the liquid metal is poured, it comes in contact with the chills. Due to rapid heat transfer, a fast moving solidification front moves towards the centre, not giving any chance for the secondary dendrites to form. So directional solidification is achieved by increasing the solidification rate. These chills must be dry to avoid the formation of blow holes. Due to rapidly moving solidification fronts towards centre, there will be some contraction stress associated with it. Especially in case of chills these stress will multiply at the centre. As a result of that cracking appears during the last stage of solidification at the centre. This defect is called hot tear (a metallurgical defect).

If the casting is big or when it is very complex, external chills alone may not completely avoid the formation of secondary dendrites. In such cases internal chills are used. Internal chills and cores are supported by chaplets. Both chills (internal) and chaplets must be pure and are supposed to fuse with the liquid metal, unfused internal chills are highest defect in casting.

Padding is applied to the patterns to promote directional solidification. Padding is excess metal added to the casting to develop temperature gradients for directional solidification. Directional solidification can also be achieved by decreasing the solidification rate called inoculation. Small amount of another metal (inoculant) is added before pouring the liquid metal into the mould cavity. These metals act like catalyst which retards the formation of secondary dendrites. Examples are, Sodium (Na) is used for Aluminium casting, Magnesium (Mg) is used for cast irons etc.

3.5.3 Pouring Temperature

Section sensitivity is defined as the minimum thickness section attached to the casting that can be filled completely by liquid metal. Higher is the pouring temperature better will be the section sensitivity but the liquid metal will undergoes large amount of shrinkage. As a result of that riser design will become very complex. If the pouring temperature is low there will be defects like cold shut and misruns, appears. When two streams are not able to fuse together, this defect is called cold shut. Misrun appears where all the details of the castings are not filled completely.

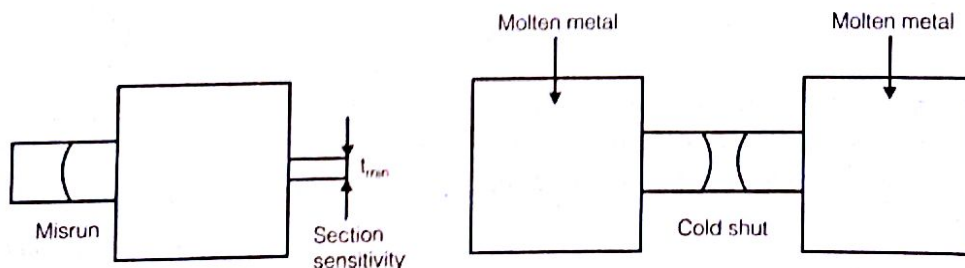


Fig. 3.14 : Cold Shut and Misrun

These defects appear due to poor fluidity. Fluidity is the ability of liquid metal to flow. This can be quantified by spiral test. A spiral mould is being prepared and liquid metal is poured through the centre. How much distance liquid metal covers in the mould before solidification, is the measure of fluidity. If the cross-section area of this cavity is constant, it is called rod test and if the cross-section area is variable, it is called V-test. When the pouring temperature is very high water disintegrates into H_2 and O_2 and as H_2 comes out it leaves large number of fine holes on the surface of casted part. This defect is called pin hole porosity. So the temperature at pouring must be optimum.

3.6 DIE CASTING

In this process the mould is made up of some permanent material like cast iron, die steels, copper and aluminum. Two halves can either be placed horizontally or vertically and when liquid metal is poured under gravity it is called gravity die casting and when liquid metal is injected into this permanent mould, it is called pressure die casting. It is having following advantages

- Same mould can be reused again and again. This increases the production rate as high as 150-250 casts per hour.
- Dimensional tolerance is of the order of 0.001 to 0.003 inch.
- Rapid cooling produces high strength.
- Better section sensitivity but after some amount of usage, mould contamination takes place i.e. a portion of metal will stick to the mould. This has to be removed by abrasive jet machining (AJM). If atmospheric gases are trapped within the liquid metal, it cannot come out, because these moulds have zero permeability. In gravity die casting there are high chances of atmospheric gases getting trapped.

Pressure die casting :

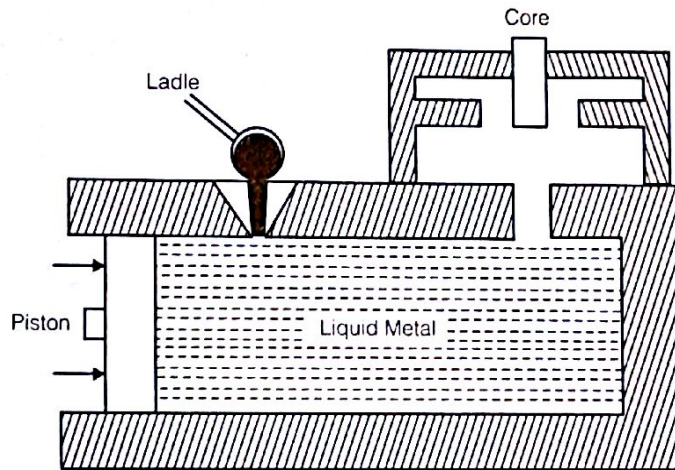


Fig. 3.15 : Cold Chamber Die Casting

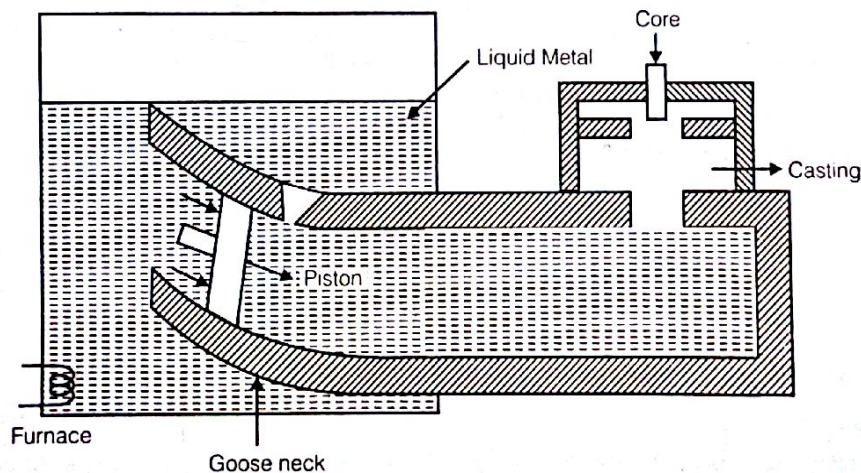


Fig. 3.16 : Hot Chamber Die Casting

In pressure die casting the water cooled dies are lubricated and then damped together. The molten metal is then injected under pressure. This pressure creates turbulence in the liquid metal and as a result of that air will be trapped within the liquid metal. In cold chamber die casting metal is liquified separately and brought to die using crucible and ladle. Since liquid metal comes in contact with atmosphere the chances of air trappment is very high.

In hot chamber die casting process furnace is a part of die and liquid metal is not exposed to atmosphere. But since a major portion of the assembly is dipped into the liquid metal, this arrangement is suitable to cast materials which has low melting point. Hot chamber die casting offers fast cycling time (upto 15 cycles/min). Hot chamber die casting can not be used for casting Aluminium alloys because the material has a tendency to pick up some iron due to extended contact with the casting equipment.

3.7 CENTRIFUGAL CASTING

3.7.1 True Centrifugal Casting

In this process a metallic mould (in two parts with flange) is rotated at 3000 rpm using a rotating device. Liquid metal is then poured into it at the centre. The mould is slightly inclined from the horizontal so that the liquid metal covers the entire working length of the mould. Percentage yield in casting is defined as the ratio of useful material to the total liquid material poured into the cavity i.e. useful material after removing risers, gates etc. The percentage yield of true centrifugal casting is around 95-98% because neither riser, nor cores are used in casting and only lighter impurities which settles at the inside surface are removed. Coarse grains settles down at the outside surface due to higher centrifugal force. The grains towards centre will be finer and finer, such surfaces are called jagged surfaces. Composite pipe, large ceramic and cast iron pipes are made by this process. Due to permanent material of mould, higher cooling rates will be experienced by the material which produces relatively fine grain structure. So castings will be strong.

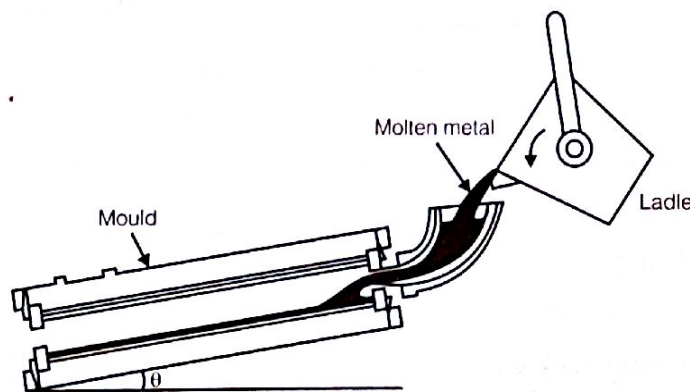


Fig. 3.17 : True Centrifugal Casting

3.7.2 Semicentrifugal Casting

In this process mould is placed on the horizontal plane and it is rotated along the vertical axis. The outer portions of the mould will be filled by purely centrifugal action and as the liquid metal approaches towards centre, the centrifugal component decreases and gravity

component increases. The central portion is purely filled by gravity. The speed of rotations and percentage yield is lower than true centrifugal casting. Wheels, pulleys etc. are made by this process.

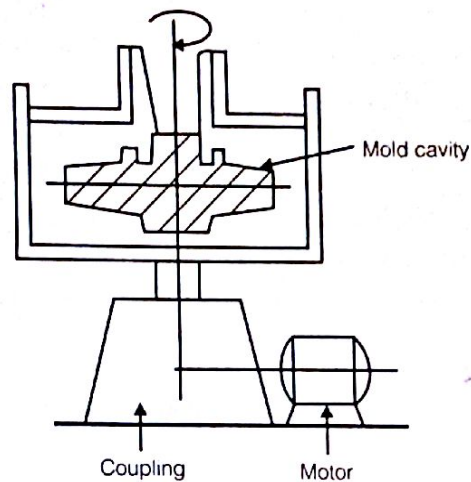


Fig. 3.18 : Semicentrifugal Casting

3.7.2 Centrifuging

As shown in figure 3.19 that a number of castings are placed on the periphery of a drum and are connected to central sprue through individual gates. After the solidification, gating system is disconnected to get the casted part. The percentage yield in this case is only 5-10% and speed of rotation is much lower. The castings need not to be axisymmetric and the process is primarily used in making patterns for investment casting.

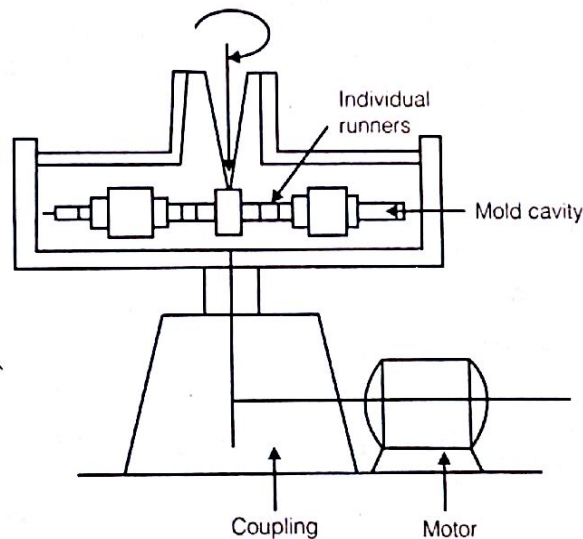


Fig. 3.19 : Centrifuging

3.8 SLUSH CASTING

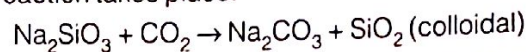
Gold jewellery, lamp bases, statue and other brass items are made by this process. Liquid metal is poured into the die cavity and since solidification will start from the surface, without completely solidifying the liquid metals, the mould is inverted and excess metal is removed from the cavity.

3.9 BLOW MOULDING

Glass and plastic bottles, bulb etc are moulded by this process. Glass or plastic in the semi viscous form (called gob) is placed in the die and air is blown into the die. As a result of that material takes the shape of die.

3.10 SODIUM SILICATE (CO₂) MOULDING

The thumb rule is that harder the mould, better will be the finish and dimensional tolerance and minimum will be the defects such as blow holes. While preparing the mould around 3-4% Na₂SiO₃ (also known as water glass) is mixed with the sand. CO₂ gas is then passed through the mould and following reaction takes place.



This produces very hard mould. Liquid metal is then poured into the cavity and after solidification mould is broken to get the final product out although harder mould is having advantages but it should be noted that the collapsibility to such moulds will be very poor.

3.11 SHELL MOULDING

Shell moulding produces better surface finish and close dimensional tolerances. The process involves following steps:

1. A pattern made up of some permanent material cast iron is heated to around 230-315°C. It is then clamped over a box containing Silica, Phenolic resins and Alcohol. No water is used in preparing the sand mixture.

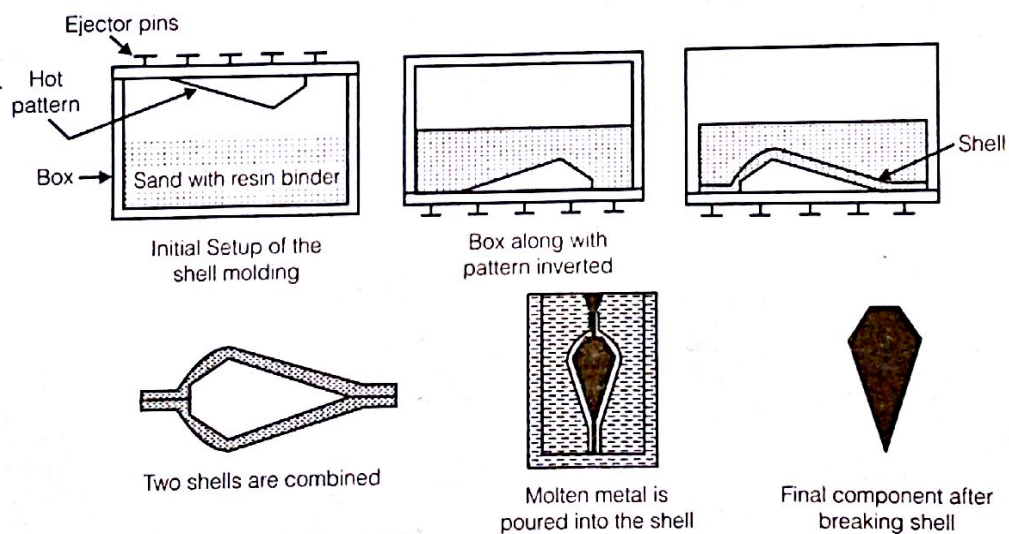


Fig. 3.20 : Shell Moulding

2. The box is then inverted and the sand is allowed to fall over the hot pattern. Depending upon the dwell time a thickness of sand will stick to the metal pattern. The thickness of shell is proportional to the dwell time.
3. The pattern along with shell is baked in an oven at around 300°C. This curing process makes the shell rigid.
4. There are ejector pins over the pattern and by hitting them to ground, shell is taken out.
5. Two or more such shells are joined together either by thermo setting plastic are clamped together.

6. Liquid metal is then poured into the shell cavity. This shell provides easy escape of gases which develops due to mould-metal reaction.

3.12 INVESTMENT CASTING

Investment casting produces better tolerances compared to shell moulding. This process is also used to produce intricate shapes which are not symmetrical. One of the application of this process is in making jet engine blades. The pattern is made of either wax or mercury. When it is made of wax, it is called lost wax method and when the pattern material is mercury, it is called mericast process. The process can be understood by following steps.

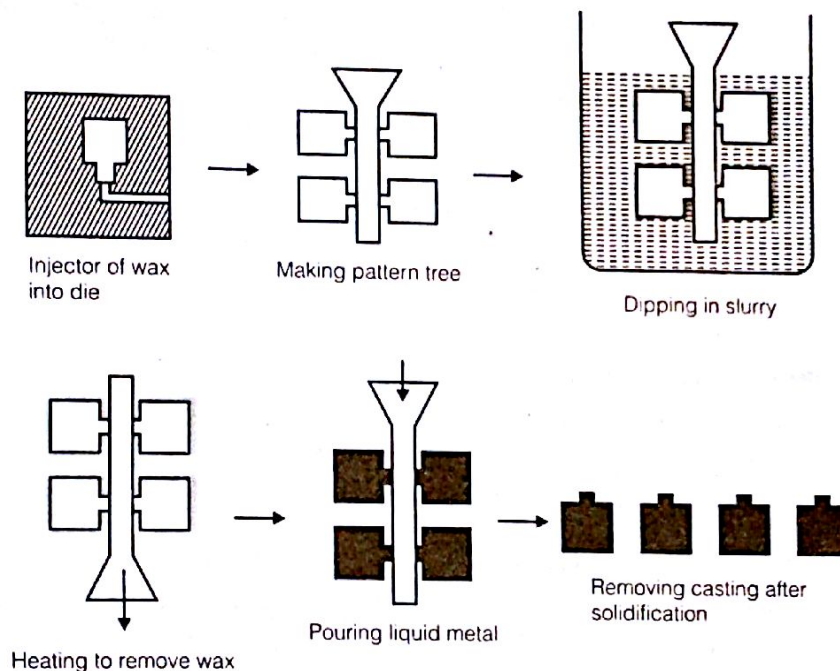


Fig. 3.21 : Investment Casting Procedure

1. Wax is initially injected into a die to make the pattern.
2. A number of these patterns are joined together with a central sprue in the form of a tree.
3. Since workers handle these patterns, it may become dirty. This pattern tree is dipped into alcohol to clean it.
4. Pattern tree is dipped into a slurry which contains water. After removing it from slurry it is dried. The tree is again dipped and then dried. By repeating this procedure for some times a layer of sand (shell) will appear over the pattern.
5. Shell is heated to remove wax from it.
6. The shell is then fired in furnace at 550-1100°C. This ensures complete removal of wax and also gives strength to the shell.
7. Pour the liquid metal when the shell is still hot otherwise shell will catch moisture from the surroundings.
8. After solidification shell is broken to get the final product.

3.13 TYPES OF CASTING DEFECTS

In the previous discussions, defects like cold shut, misrun, hot tear, shrinkage cavity, sand inclusion, blow holes, pin hole porosity and gas holes are discussed. Following are some other important defects.

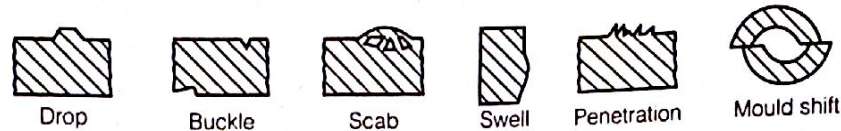


Fig. 3.22

Drop : Irregular projections on the top of casting caused by dropping of sand from cope.

Buckle : v-shaped depressions occurring on flat castings due to expansions of sand at the mould face before liquid metal solidifies.

Scab : Protruding surface of casting at roof.

Swell : Liquid metal displaces the sand at the wall regions due to hydrostatic pressure.

Penetration : Due to improper ramming of sand, liquid metal penetrates into the sand.

Mould shift : Due to misalignment between the two halves.

3.14 TYPES OF FURNACES

1. Open-hearth (acid and basic)
2. Electric-arc (acid and basic)
3. Converter (acid side-blow)
4. Electric induction (acid and basic)

The distinction between acid and basic practice is in regard to the type of refractories used in the construction and maintenance of the furnace. Furnaces operated by the acid practice are lined with silica base (SiO_2) refractories, and the slags employed in the refining process have a relatively high silica content. Basic furnaces, on the other hand, use a basic refractory such as magnesite or dolomite base and have a high lime (CaO) content in the slag. The choice of furnace and melting practice depends on many variables, including :

1. The plant capacity or tonnage required.
2. The size of the castings
3. The intricacy of the castings
4. The type of steel to be produced, i.e., whether plain or alloyed, high or low carbon, etc.
5. The raw materials available and the prices thereof.
6. Fuel or power costs.
7. The amount of capital to be invested.
8. Previous experience.

Generally, the open-hearth furnace is used for large tonnages and large castings, and the electric furnace for smaller heats or where steels from widely different producers is produced. Special steels or high-alloy steels are often produced in an induction furnace. The converter is used where space is limited and almost continuous pouring is desired.

3.15 METALLURGY OF CAST STEEL

3.15.1 Composition

Cast steel are basically an alloy of iron and carbon. In addition to carbon, which imparts basic properties to steel, the other elements that are normally present in wrought steel are also found in cast steels. These include manganese, silicon, phosphorus and sulphur. These elements usually fall in the following ranges:

Manganese (%)	0.5 - 1.0
Silicon (%)	0.2 - 0.8
Phosphorus (max %)	0.05
Sulphur (max %)	0.06

3.15.2 Melting of Cast Irons (Cupola)

Widespread use of the cupola for gray-iron melting rests upon its unique advantage, which includes :

1. Continuous melting : Foundry production is facilitated since a ladle of molten iron may be tapped from the furnace at regular intervals. The flow of molten metal and moulds for pouring may be synchronized for quantity production as required by the automotive, agricultural equipment, and similar industries.
2. Low cost of melting : Raw materials and operating costs are lower than any other type of melting furnace producing equivalent tonnage.
3. Chemical-composition control is possible by proper furnace operation with continuous melting.
4. Adequate temperature control for fluidity in pouring castings can be obtained.

Certain limitations also are characteristic of the cupola furnace. Low carbon percentages in the iron below about 2.80% C are difficult to attain, because of direct contact of molten iron and the carbonaceous fuel.

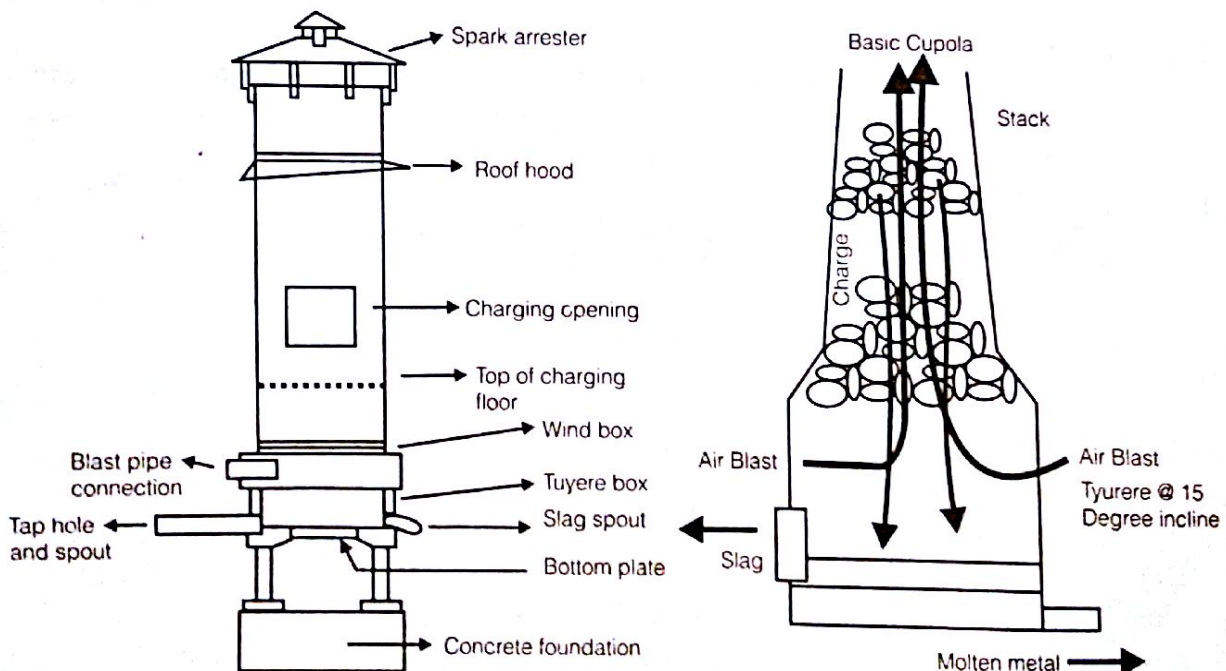


Fig. 3.23 : Cupola

3.15.3 Steps in Operation

A cupola heat includes not only the actual melting operation but all the operations which precede and follow the period during which iron is being melted. A certain cycle of events occurs each time a heat is made, including the following :

1. Preparation of the refractory lining, bottom, and taphole and slag hole.
2. Lighting and burning in the coke bed.
3. Charging
4. Melting
 - (a) Starting the air blast (b) Charging
5. Tapping and slogging
6. Dropping the bottom

Each step above is an important one, and must be properly carried out for a successful heat.

3.16 METHODS OF PURIFYING MATERIAL

1. **Zone refining** : Material is liquified and poured into a mould cavity. Heavier impurities will settle down and lighter impurities will float. By cutting the casted part from top and bottom these impurities are removed. The material is then heated again and then poured into mould. This process is repeated again and again. By this way we approach pure form of material.
2. **Pfann's method** : This process is primarily used to purify steels. Material is heated on one side carbon particles will start diffusing on the other side. Heaters are slowly moved towards other side, so carbon will be accumulated on one side. This portion is being cut and the process is then repeated.



Fig. 3.24 : Pfann's method

Example : 3.6

Design a sprue for avoiding aspiration to deliver liquid iron at a rate of 20 kg/s. Neglecting frictional and orifice effects. Take density of molten iron as 7800 kg/m^3 . The height of pouring basin is 9 cm and height of sprue is 25 cm.

Solution :

The heights of basin and sprue are 9 cm and 25 cm. So the ratio of areas of sprue at inlet and outlet without aspiration effect is

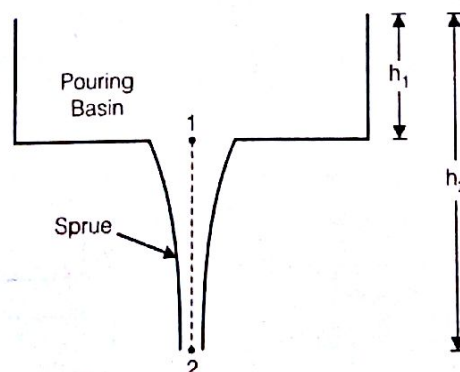


Fig. 3.25

$$\frac{A_1}{A_2} = \sqrt{\frac{h_2}{h_1}}$$

$$\therefore h_1 = 9 \text{ cm}, h_2 = 9 + 25 = 34 \text{ cm}$$

$$\frac{A_1}{A_2} = \sqrt{\frac{34}{9}} = 1.94365$$

Volume flow rate

$$Q = \frac{\dot{m}}{\rho} = \frac{20}{7800} \text{ m}^3/\text{s}$$

Velocity at point '1'

$$V_1 = \sqrt{2gh} = \sqrt{(2 \times 9.81 \times 0.09)}$$

$$= 1.33 \text{ m/s}$$

$$Q = A_1 V_1$$

$$\frac{20}{7800} = A_1 \times 1.33$$

$\therefore$

$$A_1 = 1.93 \times 10^{-3} \text{ m}^2$$

$$A_2 = \frac{A_1}{1.94365} = \frac{1.93 \times 10^{-3}}{1.94365} = 9.93 \times 10^{-4} \text{ m}^2$$

$\therefore$

$$d_1 = \sqrt{\frac{4A_1}{\pi}}$$

$$= 0.0496 \text{ m} = 4.96 \text{ cm}$$

$$d_2 = \sqrt{\frac{4A_2}{\pi}}$$

$$= 0.03555 \text{ m} = 3.555 \text{ cm}$$

Example : 3.7

Calculate the gating dimensions with a gating ratio of 1 : 2 : 3 for a ductile iron casting of section thickness 12 mm weighing 30 kg. Assume a sprue height of 200 mm.

Given : Pouring time, $t = k\sqrt{W}$ (s), $k = 2.3$ for thickness = 12 mm, flow/discharge factor $C_d = 0.9$, W = weight of casting (kg), density of iron = 7900 kg/m^3 .

Solution :

Pouring time of casting

$$t = 2.3\sqrt{30} = 12.6 \text{ s}$$

$\therefore$ flow rate, $Q = C_d A V$ (at bottom of sprue)

$$\left(\frac{m}{\rho \cdot t}\right) = C_d A_s \sqrt{2gh}$$

$$\frac{30}{7900 \times 12.6} = 0.9 A_s \sqrt{2 \times 9.81 \times 0.2}$$

$$\therefore \text{sprue base area, } A_s = 1.69 \times 10^{-4} \text{ m}^2$$

$$\therefore \text{diameter of sprue base, } d_s = \sqrt{\frac{4A_s}{\pi}} = 0.01467 \text{ m} = 14.67 \text{ mm}$$

$$\begin{aligned} \text{Area of runner, } A_r &= 2 A_s \\ &= 2 \times 1.69 \times 10^{-4} \\ &= 3.38 \times 10^{-4} \end{aligned}$$

$$\begin{aligned} \text{diameter of runner, } d_r &= \sqrt{\frac{4A_r}{\pi}} \\ &= 0.02074 \text{ m} = 20.74 \text{ mm} \end{aligned}$$

$$\text{Area of gates, } A_g = 3 A_s = 3 \times 1.69 \times 10^{-4} = 5.07 \times 10^{-4} \text{ m}^2$$

$$\begin{aligned} \text{diameter of gates, } d_g &= \sqrt{\frac{4A_g}{\pi}} \\ &= 0.0254 \text{ m} = 25.407 \text{ mm} \end{aligned}$$

Example : 3.8

Determine the riser size for a cylindrical riser for plate like steel casting with 300 mm × 200 mm × 25 mm. Check for pipe height in the riser and make suitable modification in riser design. Take $V_r/V_c = 0.26$ and percentage shrinkage for steel as 7.

Solution :

$$\therefore \left(\frac{A}{V} \right)_{\text{Casting}} = \frac{2 \times 300 \times 200 + 25 \times 300 \times 2 + 25 \times 200 \times 2}{300 \times 200 \times 25} = \frac{145000}{1500000} = 0.0967$$

$$\text{Volume of riser, } V_r = 0.26 \times 1500000 = 390000 \text{ mm}^3$$

For side placement of riser, $d = h$

$$V_r = \frac{\pi}{4} d^3 = 390000$$

$d_r = 79.2 \text{ mm}$ which is far greater than the thickness of casting.

$$\left(\frac{A}{V} \right)_r = \frac{6}{79.6} = 0.07537 (< 0.0967)$$

Solidification time justify this placement

$$\text{for top placement} \quad h = \frac{d}{2}$$

$$V_r = \frac{\pi}{4} d^2 \cdot \frac{d}{2} = 390000$$

$d_r = 99.77 \text{ mm}$ (less than the cross-section dimensions of casting)

$$\left(\frac{A}{V} \right)_r = \frac{6}{d_r} = 0.06014 (< 0.0967)$$

This time is also justifying this place. So put the riser into this position.

$$\text{Height of riser} \quad h = \frac{d}{2} = \frac{99.77}{2} = 49.885 \text{ mm}$$

Pipe height: We know that pipe cavity compensate the shrinkage allowance which is around $1/6^{\text{th}}$ of riser volume. Let the new modified height of riser is H .

$$\therefore V_s = \frac{7}{100} \times 300 \times 200 \times 25 = 105000 \text{ mm}^3$$

$$\frac{1}{6} \cdot \frac{\pi}{4} \cdot d_r^2 \times H = 105000$$

$$H = \frac{24 \times 105000}{\pi \times (99.77)^2} = 80.6 \text{ mm}$$

Hence the new height of riser should be more than 80.6 mm in order to avoid pipe extension in to the casting.

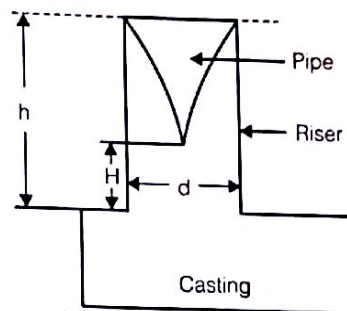


Fig. 3.26

Example : 3.9

Design a down sprue, avoiding aspiration, as shown in fig. 3.27, to deliver liquid cast iron ($\rho_m = 7800 \text{ kg/m}^3$) at a rate of 10 kg/s against no head at the base of the sprue. Neglect the friction and orifice effects.

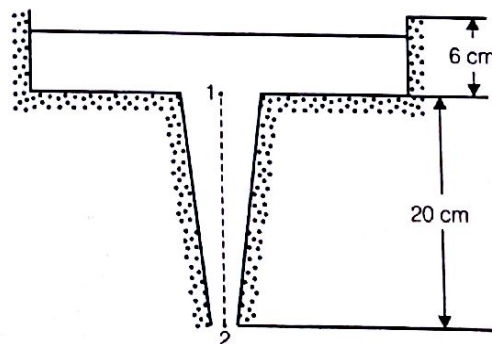


Fig. 3.27

Solution :

In order to avoid aspiration effect

$$\therefore \frac{A_1}{A_2} = \sqrt{\frac{h_2}{h_1}}$$

where A_1 and A_2 are cross-sectional areas at point 1 and 2.

$$h_2 = 20 + 6 = 26 \text{ cm}$$

$$h_1 = 6 \text{ cm}$$

$$\therefore \frac{A_1}{A_2} = \sqrt{\frac{26}{6}} = 2.08167$$

The velocity at 1 $V_1 = \sqrt{2gh_1} = \sqrt{2 \times 981 \times 6}$

$$V_1 = 108.5 \text{ cm/s}$$

Volume flow rate $\dot{Q} = \frac{\dot{m}}{\rho} = \frac{10}{7800} = \frac{1}{780} \text{ m}^3/\text{s}$

$$Q = \frac{10^6}{780} = 1282.05 \text{ cc/s}$$

$$\therefore Q = A_1 V_1$$

$$1282.05 = A_1 \times 108.5$$

$$A_1 = 11.816 \text{ cm}^2$$

$$d_1 = \sqrt{\frac{4A_1}{\pi}} = 3.88 \text{ cm}$$

$$A_2 = \frac{A_1}{2.08167} = \frac{11.816}{2.08167} = 5.6762 \text{ cm}^2$$

$$d_2 = \sqrt{\frac{4A_2}{\pi}} = 2.69 \text{ cm}$$

○○○○

PRACTICE QUESTIONS

1. Consider the following ingredients used in molding.

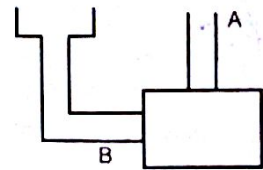
- | | |
|------------------------|--------------------|
| 1. Dry silica sand | 2. Clay |
| 3. Phenol formaldehyde | 4. Sodium silicate |

Those used for shell mould casting include

- | | |
|----------------|-------------------|
| (a) 1, 2 and 4 | (b) 2, 3 and 4 |
| (c) 1 and 3 | (d) 1, 2, 3 and 4 |

2. A sand casting mould assembly is shown in the given figure. The elements marked A and B are respectively.

- | | |
|---------------------|----------------------|
| (a) Sprue and riser | (b) Ingate and riser |
| (c) Drag and runner | (d) Riser and runner |



3. Hardness of green sand mould increases with

- (a) Increase in moisture content beyond 6 percent.
 (b) Increase in permeability
 (c) Decrease in permeability
 (d) Increase in both moisture content and permeability.

4. In solidification of metal during casting, compensation during solid contraction is:

- (a) Provided by the oversize pattern
 (b) Achieved by properly placed risers
 (c) Obtained by promoting directions solidifications
 (d) Made by providing chills

5. Match **List-I** (Moulding process) with **List-II** (Binding agent) and select the correct answer using the codes given below the lists:

List-I

- A. Green sand
 B. Cores sand
 C. Shell moulding
 D. Carbondioxide process

List-II

1. Silicate
 2. Organic
 3. Clay
 4. Plaster of paris
 5. Plastic

Codes:

	A	B	C	D
(a)	3	2	5	1
(b)	3	2	4	1
(c)	2	3	5	4
(d)	2	3	4	5

6. In which of the following are metal moulds used?

- | | |
|-------------------------|--------------------|
| (a) Green sand mould | (b) Dry sand mould |
| (c) Die casting process | (d) Loam moulding |

7. Gray cast iron blocks $200 \times 100 \times 10$ mm are to be cast in sand moulds. Shrinkage allowance for pattern making is 1%. The ratio of the volume of pattern to that of the casting will be

- | | |
|----------|----------|
| (a) 0.97 | (b) 0.99 |
| (c) 1.01 | (d) 1.03 |

8. Which one of the following is the correct statements? Gate is provided in moulds to
- feed the casting at constant rate
 - give passage to gases
 - compensate for shrinkage
 - avoid cavities
9. Volume of a cube of side 'i' and volume of a sphere of radius 'r' are equal. Both the cube and the sphere are solid and of same material. They are being cast. The ratio of the solidification time of the cube to the same of sphere is

(a) $\left(\frac{4\pi}{6}\right)^3 \left(\frac{r}{i}\right)^6$

(b) $\left(\frac{4\pi}{6}\right) \left(\frac{r}{i}\right)^2$

(c) $\left(\frac{4\pi}{6}\right)^2 \left(\frac{r}{i}\right)^3$

(d) $\left(\frac{4\pi}{6}\right)^2 \left(\frac{r}{i}\right)^4$

10. The pattern adopted for those casting where there are some portions which are structurally weak and are likely to break by the force of ramming are called:

- Loose piece pattern
- Follow board pattern
- Skeleton pattern
- Single piece Pattern

11. In a sand casting operation, the total liquid head is maintained constant such that it is equal to the mould height. The time taken to fill the mould with a top gates is t_A . If the same mould is filled with a bottom gate, then the time taken is t_B . Ignore the time required to fill the runner and frictional effects. Assume atmospheric pressure at the top molten metal surfaces. The relation between t_A and t_B is

(a) $t_B = \sqrt{2} t_A$

(b) $t_B = 2t_A$

(c) $t_B = \frac{t_A}{\sqrt{2}}$

(d) $t_B = 2\sqrt{2}t_A$

12. Plastic bottles are made using

- Blow moulding
- Injection moulding
- Preform moulding
- Slush casting

13. While cooling, a cubical casting of side 40 mm undergoes 3%, 4% and 5% volume shrinkage during the liquid state, phase transition and solid state, respectively. The volume of metal compensated from the riser is

(a) 2%

(b) 7%

(c) 8%

(d) 9%

14. If the melting ratio of a copula is 10:1, then the coke requirement for one ton melt will be:

(a) 0.1 ton

(b) 10 tons

(c) 1 ton

(d) 11 tons

15. Consider the following statements:

Assertion(A): Steel can be melted in hot blast cupola.

Reason(R): In hot blast cupola, the flue gases are used to preheat the air blast to the cupola so that the temperature in the furnace is considerably higher than that in a conventional cupola.

- Both A and R are individually true and R is the correct explanation of A.
- Both A and R are individually true and R is not the correct explanation of A.
- A is true but R is false
- A is false but R is true

16. Which of the following are in the requirements of an ideal gating system?

1. The molten metal should enter the mould cavity with as high a velocity as possible
2. It should facilitate complete filling of the mould cavity
3. It should be able to prevent the absorption of air or gases from the atmosphere by the metal while flowing through it.

Select the correct answer using the codes given below:

- (a) 1, 2 and 3 (b) 1 and 3
(c) 2 and 3 (d) 1 and 2

17. **Assertion(A):** The rate of flow metal through sprue is NOT a function of sprue, runner and gate.

Reason(R): If respective cross-sectional areas of sprue, runner and gate are known, the system is known as unpressurised gating system.

- (a) Both A and R are individually true and R is the correct explanation of A.
(b) Both A and R are true and R is not the correct explanation of A.
(c) A is true but R is false
(d) A is false but R is true

18. In gating system design, which one of the following is the correct sequence of calculations? pouring time, pouring basin and sprue sizes are calculated?

- (a) Choke area- pouring time- pouring basin- sprue
(b) Pouring basin-sprue-choke area-pouring time
(c) Choke area- sprue-pouring basin- pouring time
(d) Pouring basin- pouring time-Choke area-sprue.

19. A gating ratio of 1:2:4 is used to design the gating system for a casting. This gating ratio refers to the cross-sectional areas of the various parts of the gating system.

1. Down sprue
2. Runner bar
3. Ingates

The correct sequence of the above elements in the ratio 1:2:4 is

- (a) 1, 2 and 3 (b) 1, 3 and 2
(c) 2, 3 and 1 (d) 3, 1 and 2

20. A mould has down sprue whose length is 20 cm and the cross-sectional area of the down sprue is 1 cm^2 . The down sprue feeds a horizontal runner of length 10 cm and cross-sectional area 1 cm^2 . The volume of the mould cavity is 1000 cm^3 . The time required to fill the mould cavity will be

- (a) 4.05 s (b) 5.05 s
(c) 6.05 s (d) 7.25 s

21. Bottom gating system is sometimes preferred in casting because

- (a) It enables rapid filling of mould cavity (b) It is easier to design
(c) It provides cleaner metal (d) It reduces the risk of sand being drawn into the mould

22. A 200mm long down sprue has an area of cross-section of 1 cm^2 . It feeds a horizontal sprue which meets the down sprue (i.e. at the beginning of the down sprue). The flow rate at the end of the down sprue is $6.5 \times 10^5\text{ mm}^3/\text{s}$. Considering the end of down sprue as a free jet, the area of the down sprue (neglecting the aspiration effect) should be

- (a) 650.0 (b) 350.0
(c) 290.7 (d) 190.0

23. Directional solidification in castings can be improved by using:
 (a) Chills and Chaplets (b) Chills and Padding
 (c) Chaplets and Padding (d) Chills, Chaplets and Padding
24. Match **List-I** (Casting) with **List-II** (Explanation) and select the correct answer using the codes given below the lists:

List-I

- A. Metallic projections
 B. Cavities
 C. Inclusions
 D. Discontinuities

List-II

1. Consists of rounded or rough internal or exposed cavities including blow holes and pin holes
 2. Formed during melting, solidification and moulding
 3. Includes single folds, laps, scars adhering sand layers and oxide scale.
 4. Include cracks, cold or hot tearing and cold shuts.
 5. Consist of fins, flash or massive projections and rough surfaces.

Codes:

	A	B	C	D
(a)	1	5	3	2
(b)	1	5	2	4
(c)	5	1	2	4
(d)	5	1	3	2

25. With a solidification factor of $0.97 \times 10^6 \text{ s/m}^2$, the solidification time (in seconds) for spherical casting of 200mm diameters is

- (a) 539 (b) 1078
 (c) 4311 (d) 3233

26. Misrun is a casting defect which occurs due to

- (a) very high pouring temperature of the metal
 (b) insufficient fluidity of the molten metal
 (c) absorption of gases by the liquid metal
 (d) improper alignment of the mould flasks

27. Scab is a:

- (a) sand casting defect (b) machining defect
 (c) welding effect (d) forging defect

28. A spherical drop of molten metal of radius 2mm was found to solidify in 10 seconds. A similar drop of radius 4 mm would solidify in

- (a) 14.14 sec (b) 20 sec
 (c) 18.30 sec (d) 40 sec

29. According to Chvorinov's equation, the solidification time of a casting is proportional to

- (a) v^2 (b) v
 (c) $1/v$ (d) $1/v^2$

Where, v = volume of casting

30. Consider the following statements

Assertion(A): Aluminium alloys are cast in hot chamber die casting machine.

Reason(R): Aluminium alloys require high melting when compared to zinc alloys.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true and R is not the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

31. Match **List-I** (Product) with **List-II** (Process of Manufacture) and select the correct answer using the codes given below the lists:

List-I

- A. Automobile piston in aluminium alloy
- B. Engine crankshaft in spheroidal graphite iron
- C. Carburettor housing in aluminium alloy
- D. Cast titanium blades

List-II

- 1. Pressure die-casting
- 2. Gravity die-casting
- 3. Sand casting
- 4. Precision investment casting
- 5. Shell moulding

Codes:

	A	B	C	D
(a)	2	3	1	5
(b)	3	2	1	5
(c)	2	1	3	4
(d)	4	1	2	3

32. Which one of the following pairs is not correctly matched?

- (a) Aluminium alloy piston pressure die casting
- (b) Jewellery..... lost wax process
- (c) Large pipes..... centrifugal casting
- (d) Large bells..... loam moulding

33. Which of the following pattern-materials are used in precision casting?

- 1. Plaster of paris
- 2. Plastics
- 3. Anodized aluminium alloy
- 4. Frozen mercury

Select the correct answer using the codes given below:

- (a) 1 and 2
- (b) 2 and 4
- (c) 3 and 4
- (d) 1 and 3

34. **Assertion(A):** Semi-centrifugal casting process is similar to true centrifugal casting except that the central core is used in it from inner surface.

Reason(R): In semi-centrifugal casting process the Axis of spin is always vertical.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true and R is not the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

35. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I

- A. Die casting
- B. Centrifugal casting
- C. Centrifuging
- D. Continuous casting

List-II

- 1. Molten metal is forced into the die under pressure
- 2. Axis of rotation doesnot coincide with axis of mould
- 3. Metal solidifies when mould is rotating
- 4. Continuously pouring molten metal into mould

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	4	3	2	1
(c)	1	2	3	4
(d)	4	2	3	1

36. **Assertion(A):** die casting yields a product of good accuracy and finish

Reason(R): low melting alloys are used in die casting

- (a) both A and R individually true and R is the correct explanation of A.
- (b) both A and R individually true and R is not the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

37. Consider the following statements:

Assertion(A): In CO_2 casting process, the mould or core attains maximum strength

Reason(R): The optimum gassing time of CO_2 through the mould or core forms Silica Gel which imparts sufficient strength to the mould or core.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true and R is not the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

38. Match the items of **List-I** (Equipment) with the items of **List-II** (Process) the process answer using the given codes

- List-I**
- P. Hot chamber machine
 - Q. Muller
 - R. Dielectric Baker
 - S. Sand Blaster

- List-II**
- 1. Cleaning
 - 2. Core making
 - 3. Die casting
 - 4. Annealing
 - 5. Sand mixing

- (a) P-2, Q-1, R-4, S-5
- (c) P-4, Q-5, R-1, S-2

- (b) P-4, Q-2, R-3, S-5
- (d) P-3, Q-5, R-2, S-1

39. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

- List-I**
- A. Hollow state
 - B. Dentures
 - C. Aluminium alloy pistons
 - D. Rocker arms

- List-II**
- 1. Centrifugal casting
 - 2. Investment casting
 - 3. Slush casting
 - 4. Shell moulding
 - 5. Gravity die casting

Codes:

	A	B	C	D
(a)	3	2	4	5
(b)	1	3	4	5
(c)	1	2	3	4
(d)	3	2	5	4

40. Which of the following are produced by slush Casting?

- (a) Hollow castings with thick walls
- (b) Hollow castings with thin walls
- (c) Thin castings
- (d) Thick castings

41. In shell moulding, how can the shell thickness be Accurately maintained?
- by controlling time during which the pattern is in contact with mould
 - by controlling time during which the pattern is heated
 - by maintaining the temperature of the pattern in the range of 175°C-380°C
 - by the type of binder used
42. An expendable pattern is used in
- slush casting
 - squeeze casting
 - centrifugal casting
 - investment casting
43. Which one of the following processes produces a casting when pressure forces the molten metal into the mould cavity?
- shell moulding
 - investment casting
 - die casting
 - continuous casting
44. Which of the following engineering materials is the most suitable candidate for hot chamber die casting?
- low carbon steel
 - titanium
 - copper
 - tin
45. Shell moulding can be used for
- producing milling cutters
 - making gold ornaments
 - producing heavy and thick walled casting
 - producing thin casting
46. Which one of the following processes consist of central sprue to feed metal into cavities through a number of radial gates?
- centrifuging
 - semi-centrifugal casting
 - true centrifugal casting
 - precision casting
47. Which of the following materials are used for making patterns in investment casting methods?
- Wax
 - Rubber
 - Wood
 - Plastic
- Select the correct answer using the codes given below:
- only 1 and 3
 - only 2 and 3
 - only 1, 2 and 4
 - only 2, 3 and 4
48. Consider the following statements:
- Zinc die casting have low strength
 - In the die casting process, very thin sections and complex shapes can be obtained easily
- Which of the statements given above is /are correct?
- 1 only
 - 2 only
 - both 1 and 2
 - neither 1 nor 2
49. Which one of the following is the correct statements in a centrifugal method?
- no core is used
 - core may be made of any metal
 - core is made of sand
 - core is made ferrous metal
50. The mould in shell moulding process is made up of which of the following?
- gypsum + setting agents
 - green sand + clay
 - sodium silicate + dried sand
 - dried silica + phenolic resin

51. Which of the following are employed in shell moulding?

1. Resin binder
2. Metal pattern
3. Heating coils

Select the correct answer using the code given below

- (a) 1 and 2 only
- (b) 1 and 3 only
- (c) 2 and 3 only
- (d) 1, 2 and 3

52. Consider the following statements in respect of investment casting :

1. The pattern or patterns is/are joined to a stalk or sprue also of wax to form a tree of patterns
2. The prepared moulds are placed in an oven and Heated gently to dry off the invest and melt out the bulk of wax

3. The metal is usually poured by placing the moulds in a vaccum chamber

which of the statements given above are correct

- (a) 1 and 2 only
- (b) 1 and 3 only
- (c) 2 and 3 only
- (d) 1, 2 and 3

53. In sand moulding the bottom most part of the flask is called

- (a) cope
- (b) cheek
- (c) drag
- (d) flask bottom

54. Moulding sands can contain following percentage of maximum quantity of moisture

- (a) 2.5%
- (b) 5%
- (c) 8%
- (d) 12%

55. The purpose of chaplets is

- (a) just like chills to ensure directional solidification
- (b) to provide efficient venting
- (c) to support the cores
- (d) to join lower and upper parts of the moulding box

56. Fluidity greatly influences by

- (a) carbon content of molten metal
- (b) melting temperature of molten metal
- (c) inoculant addition
- (d) pouring temperature of molten metal

57. The chief advantage of die casting is

- (a) possibility of incorporating thick sections in small castings
- (b) casting of inserts is possible
- (c) wide tolerances are possible
- (d) high production rates are possible

58. The purpose of inoculation is

- (a) to clean the casting
- (b) to decrease the melting temperature of a cast metal
- (c) to alter the chemical composition of a cast metal
- (d) to modify the structure and properties of a cast metal

59. The main advantage of shell moulding is that

- (a) a metallic pattern is used
- (b) the moulds are strong
- (c) thin sections can be easily obtained
- (d) highly complex sections can be easily obtained

60. Draft on pattern for casting is

- (a) shrinkage allowance
- (b) taper to facilitate its removal from mould
- (c) increase in size of cavity due to shaking of pattern
- (d) for machining allowance

61. Strength and permeability of green sand and are related
(a) grain size (b) clay-content
(c) moisture content (d) type of sand
62. Least shrinkage allowance is provided in the case of following
(a) brass (b) aluminium
(c) cast iron (d) white cast iron
63. Cores are used to
(a) make desired recess in castings (b) strengthen moulding sand
(c) support loose pieces (d) remove pattern easily
64. Shrinkage allowance is made
(a) adding to external and internal dimensions
(b) subtracting from external and internal dimensions
(c) subtracting from external dimensions and adding to internal dimensions
(d) adding to external dimensions and subtracting from internal dimensions
65. The purpose of gate is to
(a) feed the casting at a rate consistent with the rate of solidification
(b) act as reservoir for molten metal
(c) help feed the casting until all solidification takes place
(d) feed molten metal from pouring basin to gate
66. Pick up the correct statement
(a) loose piece patterns are used when the pattern can be drawn from the mould
(b) sweep patterns eliminate the need for three dimensional patterns
(c) match plate patterns are made by fastening each half of a split pattern on the same side of one plate
(d) cope and drag patterns are solid one piece patterns.
67. The lighter impurities in true centrifugal casting
(a) get collected at outer surface
(b) mix up thoroughly throughout
(c) get collected at the inner surfaces
(d) get collected in the middle portion in between inner and outer surface
68. The purpose of pouring basin is to
(a) feed the casting at a rate consistent with the rate of solidification
(b) act as reservoir of molten metal
(c) help feed the casting until all solidification takes place
(d) feed molten metal from pouring basin to gate
69. As the size of castings increase, it is often better to use increasingly
(a) fine grain (b) medium grain
(c) coarse grain (d) any one of the above
70. The purpose of riser is to
(a) feed the casting at a rate consistent with the rate of solidification
(b) act as a reservoir for molten metal
(c) help feed the casting until all solidification takes place
(d) feed molten metal from pouring basin to gate

71. Freezing ratio or relative freezing time according to Caine's equation is

(a) $\frac{A_C/V_R}{A_R/V_C}$

(b) $\frac{A_R/V_R}{A_C/V_C}$

(c) $\frac{V_C/A_C}{V_R/A_R}$

(d) $\frac{V_R/A_R}{V_C/A_C}$

72. Hot tear refers to

(a) casting defect

(b) process of fabrication

(c) process of heat treatment

(d) weathering of non-ferrous materials

73. True centrifugal casting

(a) is used to ensure purity and density at extremities of a casting

(b) is used to cast symmetrical objects

(c) is used to obtain high density and pure castings

(d) uses a heavy cast iron mould to act as chill

74. Investment casting is used for

(a) shapes which are made by difficulty using complex patterns in sand casting.

(b) mass production

(c) shapes which are very complex and intricate and can't be cast by any other method.

(d) there is nothing like investment casting

75. The materials of pattern in the case of investment casting is

(a) thermosetting resin

(b) synthetic sand

(c) wax

(d) mercury

76. Which of the following process would produce strongest components?

(a) die casting

(b) hot rolling

(c) cold rolling

(d) forging

77. The hot chamber die casting method is used to cast

(a) brass

(b) aluminium

(c) alloys of lead, tin and zinc

(d) all of the above

78. In hot chamber method of die casting

(a) only low melting point metals can be used

(b) high melting point metals can be cast

(c) die is kept hot by electrical heating

(d) die is kept cold by circulating water

79. Blind risers

(a) assist in feeding the metal into casting properly

(b) help to trap slag or other lighter particles

(c) supply the hottest metal when pouring is completed

(d) do not exit

80. In slush casting process

(a) molten metal is fed into the cavity in metallic mould by gravity

(b) metal is poured into die cavity, and after a predetermined time the mould is inverted to permit a part of metal which is still in molten state to flow out of cavity.

- (c) cavity is filled with a percolated quantity of metal and a core or plunger is inserted to force the metal into cavity
 - (d) metal is forced into mould under high pressure
- 81.** Ornamental objects, statues, toys etc. are cast by
- (a) die casting
 - (b) pressed casting
 - (c) centrifugal casting
 - (d) slush casting
- 82.** Steel and cast iron pipes are cast by
- (a) die casting
 - (b) continuous casting
 - (c) true centrifugal casting
 - (d) centrifuging
- 83.** Scabs or buckles are the casting defects
- (a) which occur due to some sand shearing from the cope
 - (b) which take the form of internal voids or surfaces depression due to excessive gaseous material not able to escape
 - (c) which occur due to discontinuity in metal casting resulting from hindered contraction
 - (d) caused by two streams of metals that are too cold to fuse properly
- 84.** Drossing in foundry practice refers to
- (a) a method of cleaning the castings
 - (b) an inspection method for castings
 - (c) a method of de-oxidation of molten metal
 - (d) the formation of oxides on the molten metal surface
- 85.** Cold shuts are casing defects
- (a) which occur due to some sand shearing from the cope surfaces
 - (b) which take the form of internal voids or surface depression due to excessive gaseous material not able to escape
 - (c) which occur due to discontinuity in metal casting resulting from hindered contraction
 - (d) caused by two streams of metals that are too cold to fuse properly
- 86.** Slag inclusion in casting is a
- (a) surface defect
 - (b) internal defect
 - (c) crack
 - (d) notch
- 87.** Jolt machines produce
- (a) uniform ramming about the pattern
 - (b) uniform ramming about the flask
 - (c) uniform distribution throughout
 - (d) pack sand loosely all around
- 88.** Blow holes are casting defects
- (a) which occur due to some sand shearing from the cope surface
 - (b) which take the form of internal voids or surfaces depression due to excessive gaseous material not able to escape
 - (c) which occur due to discontinuity in metal casting resulting from hindered contraction
 - (d) caused by two streams of metals that are too cold to fuse properly

OOOO

ANSWERS

CASTING

1. (c)	2. (d)	3. (c)	4. (a)	5. (b)	6. (c)	7. (a)
8. (a)	9. (d)	10. (b)	11. (b)	12. (a)	13. (b)	14. (a)
15. (a)	16. (c)	17. (d)	18. (a)	19. (a)	20. (b)	21. (d)
22. (c)	23. (d)	24. (c)	25. (b)	26. (b)	27. (a)	28. (d)
29. (a)	30. (d)	31. (a)	32. (b)	33. (b)	34. (b)	35. (a)
36. (b)	37. (a)	38. (d)	39. (d)	40. (b)	41. (a)	42. (d)
43. (c)	44. (d)	45. (d)	46. (a)	47. (c)	48. (a)	49. (a)
50. (d)	51. (d)	52. (d)	53. (c)	54. (c)	55. (c)	56. (d)
57. (d)	58. (d)	59. (c)	60. (b)	61. (c)	62. (c)	63. (a)
64. (d)	65. (a)	66. (b)	67. (c)	68. (d)	69. (c)	70. (b)
71. (d)	72. (a)	73. (b)	74. (c)	75. (c)	76. (d)	77. (c)
78. (a)	79. (a)	80. (b)	81. (d)	82. (c)	83. (a)	84. (d)
85. (d)	86. (b)	87. (a)	88. (b)			

Metal Cutting

In machining the total energy required is summation of energy required in plastic deformation to break crystal structure and in overcoming the friction. Cutting tools are classified into two major groups:

1. Single point cutting tools
2. Multipoint cutting tools.

Multipoint cutting tool : They have more than one cutting edge to remove excess material from the work piece. Milling cutters, drills, reamers, broaches and grinding wheels are multi point cutting tools.

Single point cutting tool : The tool terminating in a single point has been termed as single point cutting tool. The tool is made of either high carbon steel, high speed steel or carbide bar. The cutting edge is prepared by grinding. It has one cutting edge which is partially formed by the end cutting edge and largely by the side cutting edge. Its nose is given a small radius and it is never a sharp point. This imparts strength to the cutting edge and reduces the magnitude of stress over the cutting edge. The nature of single point cutting tool are presented in Fig. 4.1 and 4.2.

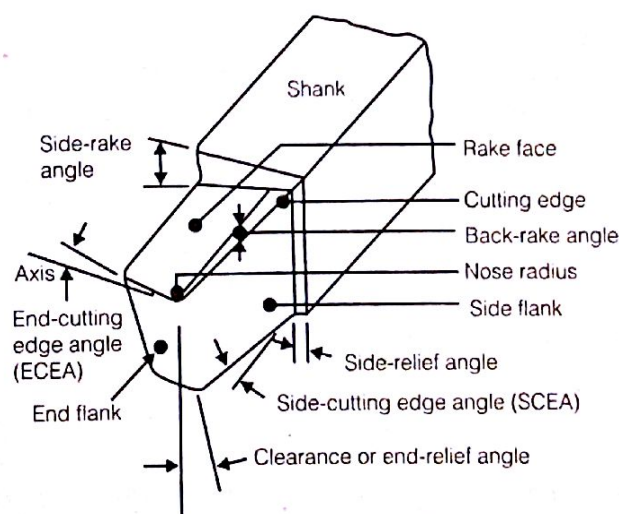


Fig. 4.1 : Single point cutting tool

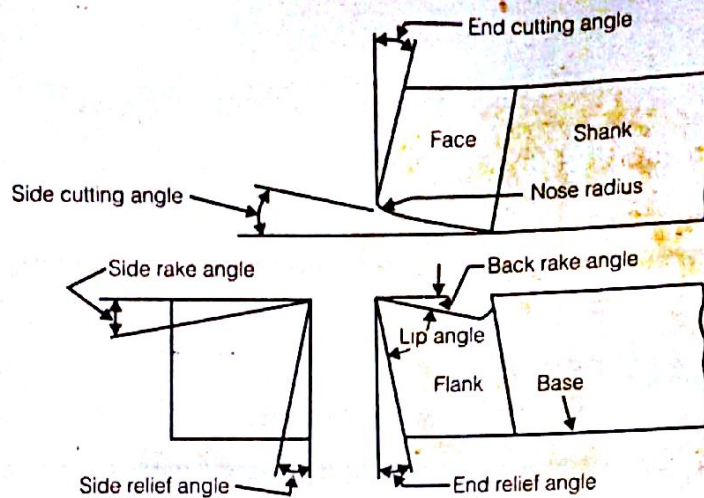


Fig. 4.2 : Representation of various angles in different views of single point cutting tool

4.1 TERMINOLOGY OF SINGLE POINT CUTTING TOOL (AS PER ASA)

4.1.1 Back rake angle

It is the angle between the line parallel to the tool axis passing through the tip and the rake face and angle is measured in a plane perpendicular to the base.

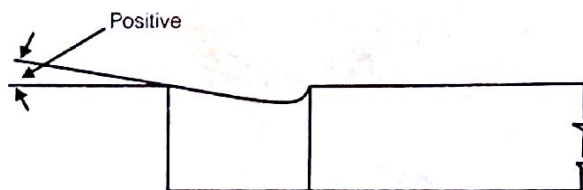


Fig. 4.3 (a) : Positive Rake angle



Fig. 4.3 (b) : Neutral Rake angle

After plastic deformation chips flow over the rake face and heavy drag exists between chip and rake face. Due to this, temperature continues to develop and the maximum temperature will appear 2-3 mm away from the cutting edge. At high temperature, carbon starts diffusing from the tool to the chip and as a result of that tool becomes weaker and weaker. Due to the drag between the chip and the tool, a portion of the tool will be carried away by the chip. This phenomenon is called diffusion wear. By increasing the Back Rake angle, chip flow will be easier, that is drag will decrease and hence the tool wear. So initially by increasing back rake angle, tool life increases.

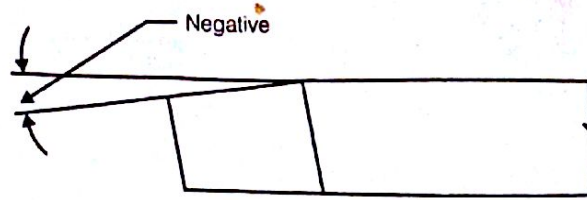


Fig. 4.3 (c) : Negative rake angle

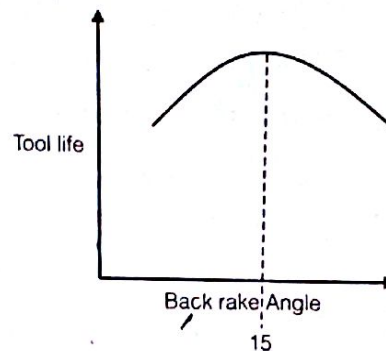


Fig. 4.3 (d) : Variation of Back rake angle with respect to tool life

While machining stronger or brittle materials, smaller rake angles are used. For ex: machining brass, zero degree rake angles are chosen. If the tool material is brittle like ceramics and carbides, negative back rake angles have to be provided because we want to make the tool stronger. By providing the negative back rake angle, energy required to overcome the friction increases which increases the overall power requirement in machining but negative rake angles are required for tool stability because due to impact created by faylite, tool may break.

When machining slots or key ways the cutting tool may be given a negative back rake and positive side rake. For machining ductile materials tool life increases by increasing back rake angle because of decrease in contact length between chip and tool over the rake face. But when this angle becomes more than a particular value, lip angle of the tool decreases. This decreases the strength of tool hence tool life decreases. This is represented in Fig. 4.3 (d). The optimum back rake angle of ductile materials is around 10-15°.

4.1.2 Side cutting edge angle (ψ)

It is the angle between the side cutting edge and the line extending the shank. The angle is measured in a plane parallel to base. Feed represents uncut chip thickness and depth of cut represents width of chip.

$$\theta \propto \sqrt{f_t}$$

θ = Maximum temperature on Rake face.

f_t = true feed or feed experienced by the cutting edge in perpendicular direction and it is equal to the uncut chip thickness

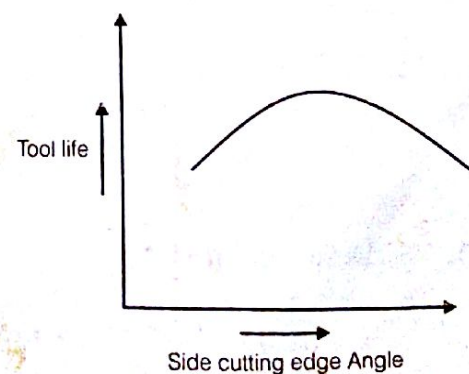


Fig. 4.4 : Variation of tool life with respect to side cutting edge angle

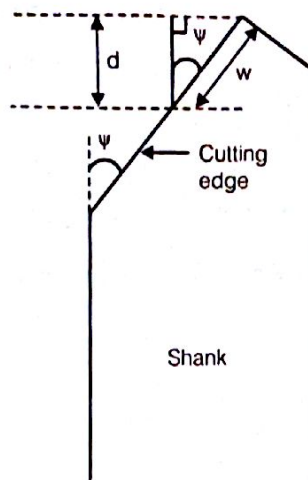


Fig. 4.5

From Fig. 4.5

$$w = \frac{d}{\cos \psi}$$

d = depth of cut

w = width of cut

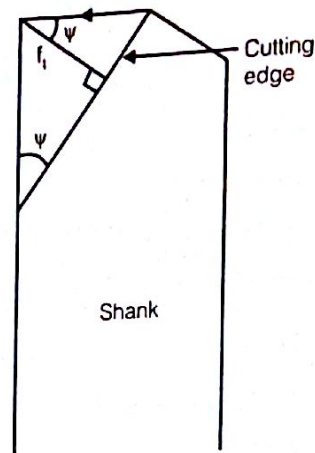


Fig. 4.6

From Fig. 4.6

$$\frac{f_t}{f} = \cos \psi$$

$$\text{True feed} = f_t = f \cos \psi$$

t_1 = uncut chip thickness.

Width of the chip is the length of the cutting edge covered by the chips and it can be observed in the analysis that as side cutting edge angle increases chips become wider. Uncut chip thickness is feed experienced by the side cutting edge in the perpendicular direction and by increasing the side cutting edge angle, chips become thinner.)

Wider chips increases the friction force so by increasing the side cutting edge angle cutting force requirement is slightly increased. But, since the heat is distributed over the larger area, peak temperature over the rake face will decrease. This will decrease the tool wear and hence increases the tool life. Side cutting edge angles increases possibility of chatter vibrations. For machining shoulders a small negative side cutting edge angle of $2^\circ - 5^\circ$ is given on tools. Normally the value of Side cutting edge angle varies between $15-30^\circ$.

4.1.3 Side Rake Angle

It is the angle between the rake face and the line passing through the tip perpendicular to the tool axis and the angle is measured in a plane perpendicular to the base. Normally this angle varies between $5-15^\circ$.

4.1.4 Side Relief Angle

It is the angle between the side flank and the line passing through the tip perpendicular to the base and the angle is measured in a plane perpendicular to the tool axis. This angle varies in the range of $5-15^\circ$. The work piece material which is going to be removed in the next revolution will try to hit the side flank due to elastic recovery of work piece material. To avoid this rubbing side relief angle is provided

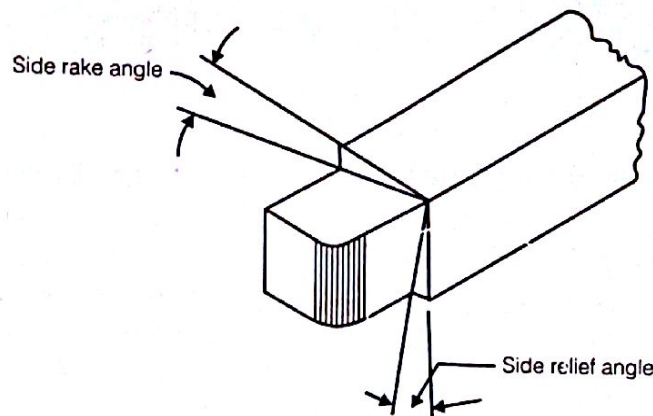


Fig. 4.7 : Representation of side rake and side relief angles

4.1.5 End Cutting Edge Angle

It is the angle between the end cutting edge and the line passing through the tip perpendicular to the tool axis and the angle is measured in a plane parallel to base. At smaller values of the angle larger forces normal to the machine surfaces are produced and the tool may chatter. Side cutting edge angle is made zero for a distance slightly greater than the feed in order to decrease rough marks due to feed marks. The normal value of this angle is in the range of 8-15°.

4.1.6 End Relief Angle (Clearance angle)

It is the angle between the end flank and the line passing through the tip perpendicular to the base and angle is measured in plane parallel to the tool axis. There will be some elastic recovery in the finished work and as a result of that it will try to rub the end flank. While machining ductile materials elastic recovery will be more so larger clearance angle has to be provided. Relief is provided to the side and end flanks in order to minimize physical interference or rubbing contact with the machine surface of work piece. Smaller relief angles do not weaken the cutting edge as much as the larger relief angles.

4.1.7 Nose Radius

Larger nose radius gives better surface finish. Increasing the nose radius also improves the tool life, so that higher cutting speeds can be employed. However the cutting force and possibility of chatter increases when the nose radius is increased excessively.

4.1.8 ASA Tool Signature

Back rake angle - Side rake angle - End relief angle - Side relief angle - End cutting edge angle - Side cutting edge angle - Nose radius.

In this system the geometry of the rake face is expressed in term of back rake angle and side rake angle.

Surface roughness:

Peak to valley height, $H_{\max} = \frac{f^2}{8R}$

f = feed, R = nose radius

Center Line Average value, $Ra = \frac{H_{\max}}{4}$

$$H_{\max} = \frac{f}{\tan \psi + \cot \psi_1}$$

ψ = Side cutting edge angle ψ_1 = End cutting edge angle

4.2 BRITISH SYSTEM

Rake angle in this system defined as the steepest slope over the rake face. It is assumed that taking this value as the rake angle gives accurate results for cutting forces. The main advantage of this system is that the specified rake angle is easy to set on a tool grinding fixture for grinding the rake face. The angle of chip flow is difficult to estimate.

4.3 NORMAL OR ORTHOGONAL RAKE SYSTEM (ORS)

A number of lines drawn perpendicular to the side cutting edge in the horizontal plane and the line which gives the maximum slope is called Normal Rake Angle (α_n). If side cutting edge angle is zero, normal rake angle is equal to the side rake angle. Tool signature in this system is given as: I- α_n - side relief angle - end relief angle - end cutting edge angle - approach angle λ .

where,

I-Angle of inclination

α_n -normal rake angle

λ -approach angle (90° - side cutting edge angle).

Angle of inclination is the angle of tool axis with cross slide motion.

For Orthogonal system I = 0

Conversion from ASA to ORS

$$\tan I = \cos \psi \tan \alpha_{ab} - \sin \psi \tan \alpha_{as}$$

$$\tan \alpha_n = \cos \psi \tan \alpha_{as} + \sin \psi \tan \alpha_{ab}$$

ψ = side cutting edge angle

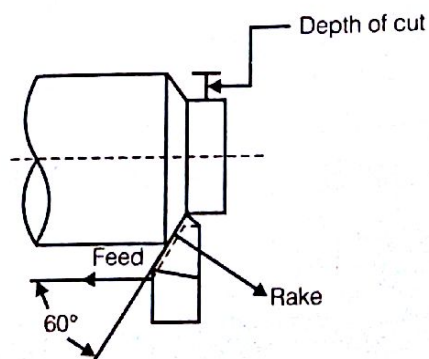
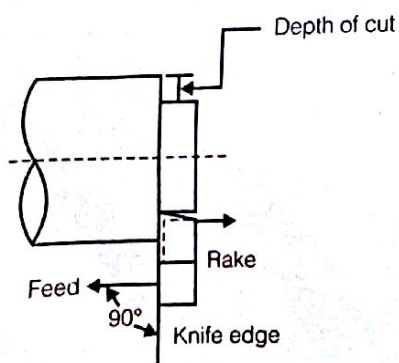
α_{ab} = back rake angle

α_{as} = side rake angle

4.4 TYPES OF METAL CUTTING PROCESS

The metal cutting processes are of two types

1. **Orthogonal cutting process** (Two dimensional cutting): It occurs when the major cutting edge of the tool is presented to the work piece perpendicular to the direction of feed motion.



2. **Oblique cutting** (Three dimensional cutting): This form of cutting occurs when the major cutting edge of the tool is presented to the work piece at an angle perpendicular to the direction of feed motion.

4.5 DISTRIBUTION OF HEAT IN METAL CUTTING

1. Primary deformation zone
2. Secondary deformation zone
3. Work-tool contact zone.

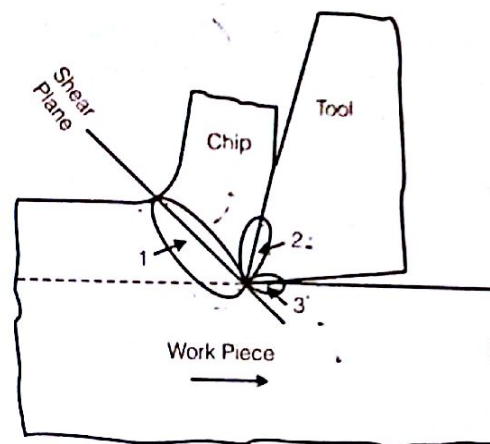


Fig. 4.8 : Representation of shear plane and shear deformation zones

There will be a region in the material in which crystal structures break. This region is called primary deformation zone and around 70-80% of the total energy supplied will be consumed in this region. This is because of the plastic deformation of metal. A portion of this energy will also come out in the form of heat. Around 20-25% energy is consumed to overcome the drag between the chip and rake face. This region is called secondary deformation zone and 100% of energy comes out in the form of heat. Although the primary deformation zone is a region, but by analytical purposes it can be approximated by a line. This plane is called shear plane. By decreasing the feed or uncut chip thickness, the value of shear plane angle will decrease, which will ultimately increase the shear plane area, so larger shear forces will be required to break the crystal structure. This increases the apparent shear strength of material. The third region is known as the work-tool contact zone; here heat is generated due to burnishing action. When the machining starts with a fresh tool the friction is almost nil, but as the interface process continues wear line grows and goes on increasing. This increases the heat generation. It should also be noted that out of total heat produced, 75-80% of that heat goes to the chip. The extent of primary zone of deformation depends on

1. Rake angle of tool
2. Cutting speed
3. Work Material characteristics and
4. Friction on rake face

4.6 TYPES OF CHIPS

4.6.1 Continuous Chips

Favourable conditions for the continuous chips to form are:

- Ductile materials ✓
- High speed ✓
- Low feed and depth of cut ✓
- High back rake angle ✓

Continuous chips start rotating with the tool and if these chips hit the finished part of the work, it spoils surface finish. So, continuous chips are broken by providing chip breakers. In drilling operation, chips are broken by providing a back feed. High back rake angle provides less resistance to flow of chips, hence favours continuous chips.

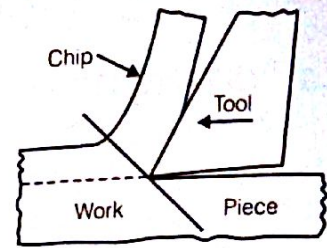


Fig. 4.9 : Continuous chip

4.6.2 Discontinuous Chips

The conditions in which discontinuous chip forms are:

- Brittle materials ✓
- Low speed ✓
- High feed and depth of cut ✓
- Low back rake angle ✓

The slight plastic deformation produced by a small advance of the cutting edge into the job leads to a crack formation in the deforming zone. With further advance, the crack travels and a small lump of materials starts moving up the rake face. The force and constraints of motion acting on the lump make the crack propagate towards the surface and thus the small segment of the chip gets detached.

As most of the heat produced in the chip is carried by the chip, the tool is heated to a longer temperature and hence has longer life.

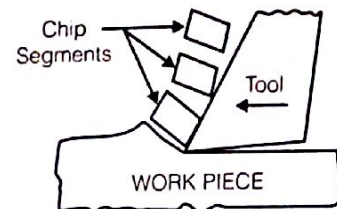


Fig. 4.10 (a) : Discontinuous chip

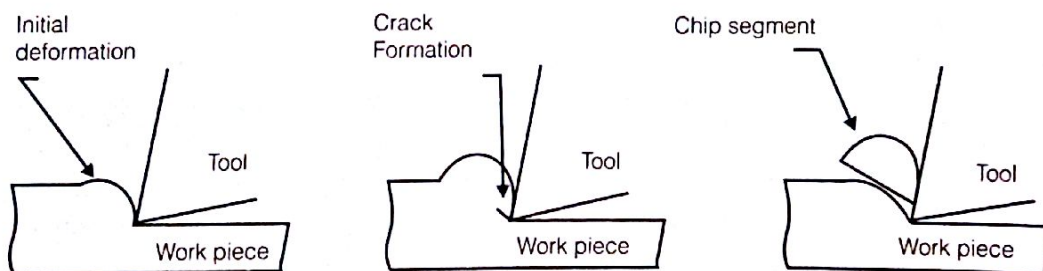


Fig. 4.10 (b) : Formation of discontinuous chips

4.6.3 Chips with build up edge

Favourable conditions for these types of chips are:

- Ductile material
- Low speed
- High feed and depth of cut

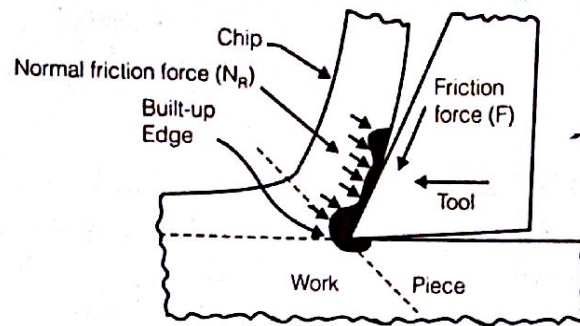


Fig. 4.11 : Chips with build up edge

Due to the low speed, heat is not being dissipated from the machining area. So, a portion of work will stick to the cutting edge called Build up Edge. Although the build up edge gives initial strength to the cutting edge but as the conditions of the build up edge continue, size of build up edge becomes bigger and bigger which changes the geometry of the cutting tool. So, a portion of this build up edge is carried away by the chip and a portion goes away with the work. In this mechanics, a portion of tool material is also lost. This type of tool wear is called Adhesion wear.

4.6.4 Chips with unusual strains

These type of chips appear, while machining the work piece materials with low thermal conductivity like titanium. Since the heat is not dissipated from the machining area, chips get accumulated in the primary deformation zone. As a result of that, shear plane angle decreases, and the requirement of cutting force increases.

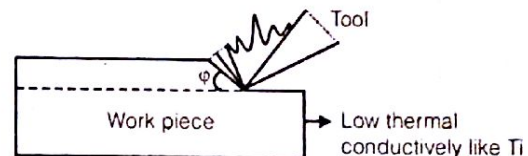


Fig. 4.12 : Chips with unusual strains

4.7 ✓ MERCHANT'S ANALYSIS FOR CHIP THICKNESS RATIO

To experimentally determine the shear angle, we have to study the geometry of chip formation..

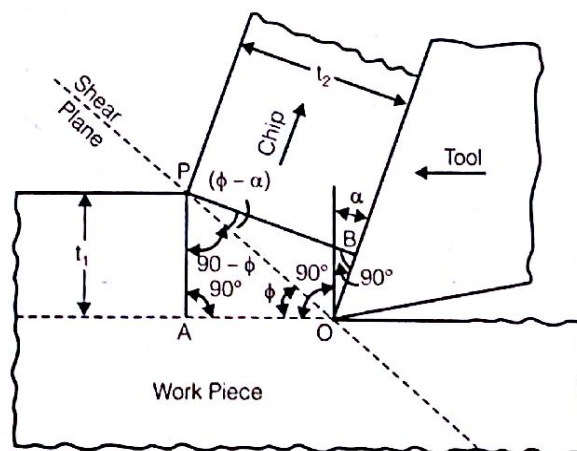


Fig. 4.13 : Orthogonal cutting operation

t_1 = Chip thickness before cutting (uncut chip thickness)

t_2 = Chip thickness after cutting

ϕ = Shear plane angle

α = Back rake angle

$$\Delta OAP : \frac{t_1}{OP} = \sin \phi \quad \dots(1)$$

$$\Delta OPB : \frac{t_2}{OP} = \sin (90 - \phi + \alpha) \quad \dots(2)$$

Divide Eq. (2) by Eq. (1)

$$\Rightarrow \frac{t_2}{t_1} = \frac{\sin (90^\circ - \phi + \alpha)}{\sin \phi}$$

$$\Rightarrow \frac{t_2}{t_1} = \frac{\sin (90^\circ - (\phi - \alpha))}{\sin \phi}$$

$$\Rightarrow \frac{t_2}{t_1} = \frac{\cos (\phi - \alpha)}{\sin \phi}$$

$$\Rightarrow \frac{t_2}{t_1} = \frac{\cos \phi \cos \alpha + \sin \phi \sin \alpha}{\sin \phi}$$

$$\Rightarrow \frac{t_2}{t_1} = \cot \phi \cos \alpha + \sin \alpha$$

$$\Rightarrow \frac{t_2}{t_1} - \sin \alpha = \cot \phi \cos \alpha$$

$$\Rightarrow \frac{t_2}{t_1} - \sin \alpha = \frac{\cos \alpha}{\tan \phi}$$

$$\Rightarrow \tan \phi = \frac{\cos \alpha}{\frac{t_2}{t_1} - \sin \alpha}$$

Always $t_2 > t_1 \rightarrow$ Chip thickness > uncut chip thickness

$$\frac{t_2}{t_1} = \text{chip thickness ratio} > 1 \quad ?$$

$$\frac{t_1}{t_2} = \text{chip reduction coefficient} < 1$$

Constancy of volume

$$l_1 t_1 w_1 = l_2 t_2 w_2$$

$$w_1 = w_2 \text{ Width kept constant}$$

$$l_1 t_1 = l_2 t_2$$

$$D = \text{diameter of work}$$

Uncut chip length $l_1 = \pi D$

Due to Compressive stresses while cutting,

$$l_2 < l_1$$

$\Rightarrow$

$$t_2 > t_1$$

4.8 DETERMINATION OF CUTTING FORCES

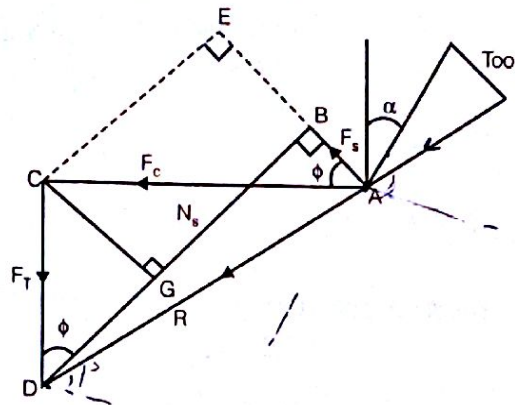


Fig. 4.14 : Representation of cutting forces

F_T = thrust force

F_C = Cutting force

Cutting force always comes in the direction of cutting and in turning operation it is tangential force acting in the vertically upward direction. Thrust force acts perpendicular to the cutting edge and enables the cutting edge to have physical contact with the work piece material. F_C and F_T are perpendicular to each other. By resolving F_T in feed direction, feed force (F_f) comes and Radial force is resolving F_T in the direction of cross slide movement i.e. toward radial direction as shown in Fig. 4.15.

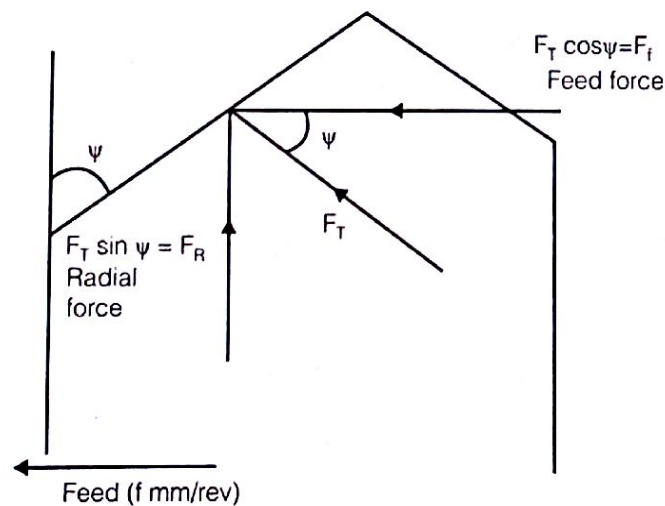


Fig. 4.15 : Feed and Radial Forces

In a true orthogonal cutting, $F_R = 0$

F_C , F_R , and F_f are perpendicular to each other.

From Fig. : 4.14

$$F_S = AE - BE$$

$$AE - CG$$

$$AE = F_C \cos \phi$$

$$CG = F_T \sin \phi$$

From Fig. : 4.17

$$OG = CH + HG$$

$$= CH + BE$$

$$CH = F_T \cos \alpha$$

$$BE = F_C \sin \alpha$$

$\Rightarrow$

$$F = F_T \cos \alpha + F_C \sin \alpha$$

$$N = CD = AG$$

$$AG = AE - EG$$

$$= AE - BH$$

$$AE = F_C \cos \alpha$$

$$BH = F_T \sin \alpha$$

$\Rightarrow$

$$N = F_C \cos \alpha - F_T \sin \alpha$$

$$\tan \beta = \frac{F}{N} = \mu$$

$$\Rightarrow \frac{F_T \cos \alpha + F_C \sin \alpha}{F_C \cos \alpha - F_T \sin \alpha} = \mu = \tan \beta$$

Divide Numerator and denominator by $F_C \cos \alpha$

$$\Rightarrow \tan \beta = \frac{\frac{F_T}{F_C} + \tan \alpha}{1 - \frac{F_T}{F_C} \tan \alpha}$$

4.10 ASSUMPTIONS OF MERCHANT'S CIRCLE

1. Cutting edge is straight and sharp.
2. Material is homogeneous.
3. Cutting is orthogonal.
4. Material is rigid and perfectly plastic.
5. Shear zone extends in a very narrow region which can be approximated by a straight line.

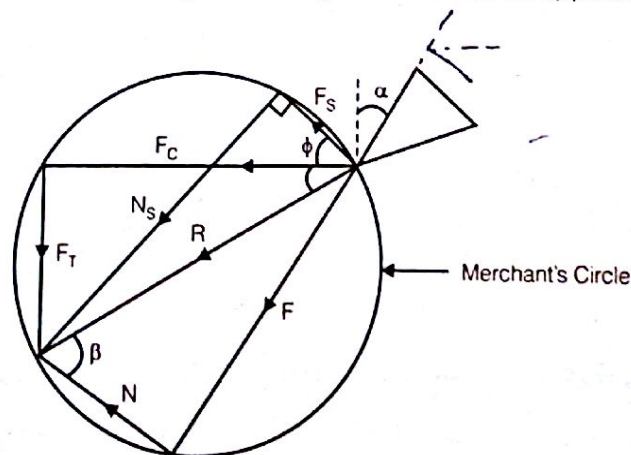


Fig. 4.18 : Merchant's circle

As soon as the cutting edge comes in contact with the work material, cutting edge will try to round off. Due to this area contact, there will be a drag between tool and work piece called PLOUGHING. These ploughing forces are proportionately insignificant when feeds and depths of cut are high but for smaller feeds; ploughing forces are proportionately very high and cannot be neglected. These theories do not consider the ploughing forces. Every material exhibits certain extent of work hardening which is also not considered in these theories.

4.11 DETERMINATION OF SHEAR ANGLE

$$\gamma = \frac{AD + DB}{CD}$$

$$\gamma = \cot(90 - \phi + \alpha) + \cot \phi$$

$$\gamma = \tan(\phi - \alpha) + \cot \phi$$

So, shear strain is

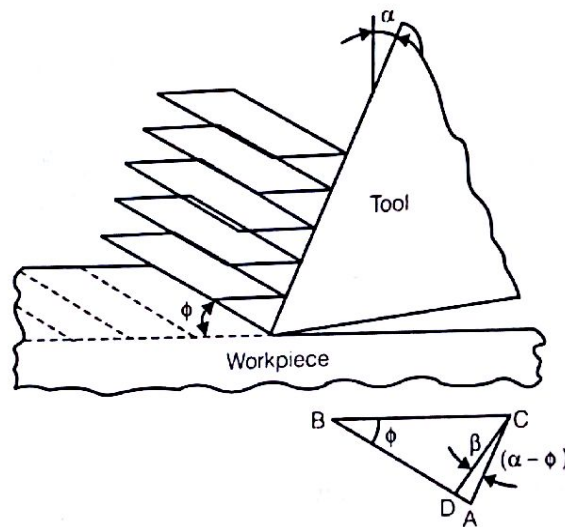


Fig. 4.19

4.12 VELOCITY TRIANGLE

Let us assume that the work material is moving against the cutting tool with a velocity V . The chip velocity V_c is the vector sum of V the velocity of uncut chip and V_s shear velocity.

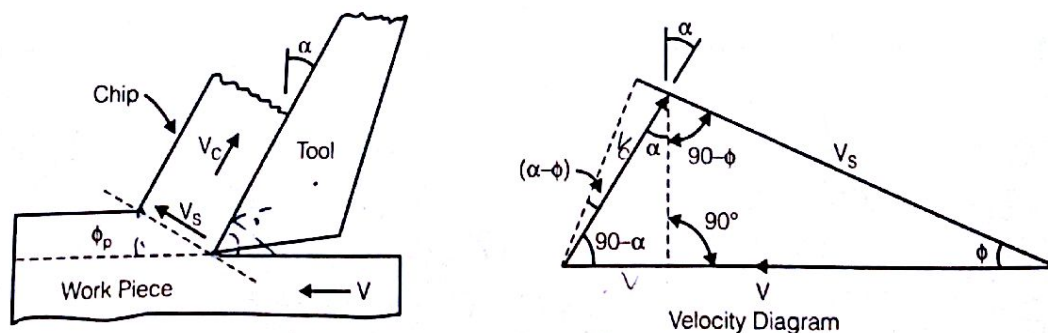


Fig. 4.20 : Representation of different velocities

$$V = \frac{\pi DN}{60}$$

V_s = Shear velocity

V_c = Chip velocity

Applying the sine rule:

$$\frac{V}{\sin(90^\circ - \phi + \alpha)} = \frac{V_c}{\sin \phi} = \frac{V_s}{\sin(90^\circ - \alpha)}$$

$$= \frac{V}{\cos(\phi - \alpha)} = \frac{V_c}{\sin \phi} = \frac{V_s}{\cos \alpha}$$

$$\text{Cutting Power} = F_c \cdot V$$

$$\text{Shear Power} = F_s \cdot V_s$$

$$\text{Friction power} = F \cdot V_c$$

$$\text{Cutting Power} = \text{Shear Power} + \text{Friction Power}$$

$$\Rightarrow F_c \cdot V = F_s \cdot V_s + F \cdot V_c$$

$$\text{Specific cutting power} = \text{cutting power} / \text{material removal rate (MRR)}$$

$$= \frac{F_c \cdot V}{\text{MRR}}$$

$$\text{MRR} = w \cdot t_1 \cdot V \text{ mm}^3/\text{min}$$

$$\Rightarrow \frac{F_c \cdot V}{w \cdot t_1 \cdot V} = \frac{F_c}{w \cdot t_1}$$

$$\text{Specific Cutting Power} = \frac{F_c}{w \cdot t_1} \quad \checkmark$$

4.13 ERNEST AND MERCHANT THEORY

It is the relationship between ϕ , α and β for minimum power consumption during machining.

$$\text{Minimum Power is } P_c = F_c \cdot V$$

$$\text{Shear force is } \tau_s \frac{w t_1}{\sin \phi} = F_s$$

Assuming τ_s to remain constant (neglecting apparent increasing in shear stress)

$$R \cos(\phi + \beta - \alpha) = F_s$$

$$R \cos(\beta - \alpha) = F_c$$

$$\frac{F_c}{F_s} = \frac{R \cos(\beta - \alpha)}{R \cos(\phi + \beta - \alpha)}$$

$$F_c = F_s \frac{\cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha)}$$

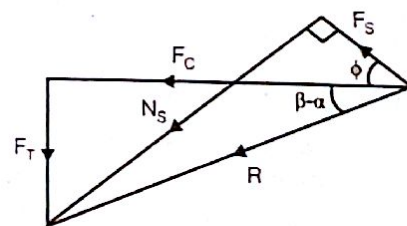


Fig. 4.21 : Representation of cutting forces

$$F_C = \tau_s \frac{wt_1}{\sin \phi} \frac{\cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha)}$$

$$P_C = F_C V = \tau_s \frac{wt_1}{\sin \phi} \frac{\cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha)} \cdot V$$

To minimize power consumption, denominator is to be maximized.

Let $X = \sin \phi \cos(\phi + \beta - \alpha)$

$$\frac{dX}{d\phi} = \cos \phi \cos(\phi + \beta - \alpha) + \sin \phi [-\sin(\phi + \beta - \alpha)] = 0$$

$$\cos(2\phi + \beta - \alpha) = 0$$

$$2\phi + \beta - \alpha = \frac{\pi}{2} \dots \dots \text{1st analysis} \quad \checkmark$$

IInd Analysis: $2\phi + \beta - \alpha = \cot^{-1}(K)$

K = machining constant

These are the procedures to calculate the shear plane angle and these formulas should be used only when sufficient data is not given in the problem to find out ϕ in a normal way.

4.14 LEE AND SHAFFER (SLIP LINE FIELD THEORY)

The theory of Lee and Shaffer was the result of an attempt to apply the plasticity theory to the orthogonal metal cutting. The assumptions are:

1. The work material ahead of the tool behaves as ideal plastic mass.
2. There exists a shear plane which separates the chip and work piece.
3. No hardening in chip occurs

Based on the following assumptions the relationship obtained is

$$\phi + \beta - \alpha = 45^\circ \quad \checkmark$$

Slip lines meet the surface at 45°

Example : 4.1

During turning process with $7 - \alpha - 6 - 6 - 8 - 30 - 1$ mm (ASA) tool the undeformed chip thickness of 0.2 mm and width of cut of 2.5 mm were used. The side rake angle of the tool was chosen such that the machining operation could be approximated to be orthogonal cutting. The tangential cutting force and thrust force were 1177 N and 560 N respectively. Calculate :

1. The side rake angle
2. Coefficient of friction at the rake face.
3. The dynamic shear strength of the work material.

Solution :

$$t_1 = 0.2 \text{ mm}$$

$$w = 2.5 \text{ mm}$$

$$I = 0$$

$$F_C = 1177 \text{ N}$$

$$F_T = 560 \text{ N}$$

1. Side rake angle

Given data

$$\tan I = \cos \psi \tan \alpha_{ab} - \sin \psi \tan \alpha_{as}$$

$$\psi = 30$$

$$\alpha_{ab} = 7$$

$$I = 0$$

⇒

$$\tan \alpha_{as} = \frac{\cos \psi \tan \alpha_{ab} - \tan I}{\sin \psi}$$

$$\alpha_{as} = 12^\circ = \text{Side rake angle}$$

2. Coefficient of friction at rake angle

$$\mu = \tan \beta = \frac{\frac{560}{1177} + \tan 7^\circ}{1 - \frac{560}{1177} \tan 7^\circ}$$

$$\mu = 0.6357$$

$$\beta = \tan^{-1}(\mu) = 32.44^\circ$$

3. Dynamic shear strength of work material

$$\frac{F_s}{\left(\frac{w \cdot t_1}{\sin \phi}\right)} = \tau_s$$

Using Ernest and Merchant's theory 1st analysis

$$\phi = \frac{90 + \alpha - \beta}{2} = \frac{90 + 7 - 32.44}{2} = 32.28^\circ$$

$$\frac{F_C}{F_s} = \frac{\cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha)} = \frac{\cos(32.44 - 7)}{\cos(32.28 + 32.44 - 7)}$$

$$F_s = \frac{F_C}{1.6909}$$

⇒

$$F_s = 696 \text{ N}$$

$$\tau_s = \frac{696 \sin(32.28^\circ)}{(2.5 \times 0.2)} = 743.5 \text{ MPa}$$

Example : 4.2

In an orthogonal cutting operation, the following data have been observed: ✓

Uncut chip thickness = 0.127 mm

Width of cut = 6.35 mm

Cutting speed = 2 m/s

Rake angle = 10°

Cutting force = 567 N

Thrust force = 227 N

Chip thickness = 0.228 mm

Determine the shear angle, the friction angle, shear stress along the shear plane, and the power for the cutting operation. Also find the chip velocity, shear strain in chip, and the strain rate.

Solution :

Given data in a cutting operation is

$$t_1 = 0.127 \text{ mm}$$

$$w = 6.35 \text{ mm}$$

$$v = 2 \text{ m/s}$$

$$\alpha = 10^\circ$$

$$F_C = 567 \text{ N}$$

$$F_T = 227 \text{ N}$$

$$t_2 = 0.228 \text{ mm}$$

1. Shear plane angle (ϕ)

$$\tan \phi = \frac{\cos \alpha}{\frac{t_2}{t_1} - \sin \alpha}$$

$$\tan \phi = \frac{\cos 10}{\frac{0.228}{0.127} - \sin 10} = 0.6073$$

$$\phi = 31.27^\circ$$

2. Friction angle (β)

$$\tan \beta = \frac{\frac{F_T}{F_C} + \tan \alpha}{1 - \frac{F_T}{F_C} \tan \alpha}$$

$$\tan \beta = \frac{\frac{227}{567} + \tan 10}{1 - \frac{227}{567} \tan 10}$$

$$\tan \beta = 0.62$$

$$\beta = 31.82^\circ$$

3. Shear stress along shear plane

$$\frac{F_S}{\left(\frac{w \cdot t_1}{\sin \phi} \right)} = \tau_s$$

$$F_S = F_C \cos \phi - F_T \sin \phi$$

$$F_S = 567 \cos 31.27 - 227 \sin 31.27$$

$$F_S = 366.8 \text{ N}$$

$$\tau_s = \frac{366.8 \times \sin 31.27}{(0.127 \times 6.35)}$$

$$\tau_s = 236.1 \text{ Mpa}$$

4. Power for cutting operations

$$P_C = F_C \cdot V$$

$$P_C = 2 \times 567 = 1134 \text{ Nm/s}$$

$$P_C = 1134 \text{ W}$$

5. Chip velocity (V_C)

$$\frac{V_C}{\sin \phi} = \frac{V}{\sin(90^\circ - \phi + \alpha)}$$

$$V_C = \frac{2 \times \sin 31.27^\circ}{\sin(90^\circ - 31.27 + 10^\circ)}$$

$$V_C = 1.114 \text{ m/s}$$

6. Shear strain in chip

$$\gamma = \tan(\phi - \alpha) + \cot \phi$$

$$\gamma = \tan(31.27 - 10) + \cot 31.27$$

$$\gamma = 2.036$$

7. Strain rate

Strain rate is the shear velocity divided by length of shear plane = $\frac{V_s}{\frac{t_1}{\sin \phi}}$

$$\frac{V_s}{\sin(90 - \alpha)} = \frac{V}{\sin(90 - \phi + \alpha)}$$

$$V_s = \frac{2 \sin(90 - 10)}{\sin(90 - 31.27 + 10)}$$

$$V_s = 2.1136 \text{ m/s}$$

$$\frac{V_s}{\frac{t_1}{\sin \phi}} = \frac{2.1136 \times \sin 31.27}{0.127 \times 10^{-3}} = 8638.62 \text{ per sec}$$

Example: 4.3

The following data from the orthogonal cutting test is available :

Rake angle = 10° , chip thickness ratio = 0.35, uncut chip thickness = 0.51, width of cut = 3 mm, yield shear stress of work material = 285 N/mm^2 , Mean friction coefficient on tool face = 0.65. Determine the (i) Cutting force (ii) Radial force (iii) Normal force on tool and (iv) Shear force on the tool.

Solution :

$$\alpha = 10^\circ$$

$$\frac{t_1}{t_2} = 0.35$$

$$t_1 = 0.51 \text{ mm}$$

$$w = 3 \text{ mm}$$

$$\tau_s = 285 \text{ MPa}$$

$$\mu = 0.65 \quad \text{Find } F_c, F_R, N, F_s$$

$$t_2 = \frac{t_1}{0.35} = \frac{0.51}{0.35} = 1.457 \text{ mm}$$

$$F_R = 0$$

$$\tan \phi = \frac{\cos 10^\circ}{\frac{1.457}{0.51} - \sin 10^\circ} = 0.367$$

$$\phi = 20.152^\circ$$

$$\tau_s \frac{Wt_1}{\sin \phi} = F_s$$

$$F_s = 1265.675 \text{ N}$$

$$F_c = \frac{F_s \cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha)}$$

$$\tan \beta = \mu = 0.65$$

$$\beta = 33.024^\circ$$

$$F_c = \frac{1265.675 \cos(33.024 - 10)}{\cos(20.152 + 33.024 - 10)}$$

$$F_c = 1597.32 \text{ N}$$

$$N = R \cos \beta$$

$$F_s = R \cos(\phi + \beta - \alpha)$$

$$N = F_s \frac{\cos \beta}{\cos(\phi + \beta - \alpha)}$$

$$N = 1455.177 \text{ N}$$

Example : 4.4

During turning a carbon steel rod of 160 mm diameter by a carbide tool of geometry; $0^\circ, 0, 10^\circ, 8^\circ, 15^\circ, 75^\circ, 0$ (mm) at speed of 400 rpm, feed of 0.32 mm/rev and 4.0 mm depth of cut, the following observations were made :

Tangential component of the cutting force, $P_z = 1200 \text{ N}$

Axial component of the cutting force, $P_x = 800 \text{ N}$

Chip thickness (after cut), $t_2 = 0.8 \text{ mm}$

For the above machining condition determine the value of

1. Friction force, F and normal force, N acting at the chip-tool interface.
2. Yield shear strength of the work material under this machining condition.
3. Cutting power consumption in kW.

Solution :

1. Since the second last value in the tool signature is very high and the side cutting edge angle as per ASA can not be so high. So, ORS tool signatures are given in the above problem. So approach angle = 75°

$$N = 400 \text{ rpm}$$

$$f = 0.32 \text{ mm/s}$$

$$\begin{aligned}d &= 4 \text{ mm} \\F_C &= 1200 \text{ N} \\F_T &= 800 \text{ N} \\t_2 &= 0.8 \text{ mm}\end{aligned}$$

Find : (i) F , N (ii) τ_s (iii) P_C

$$\alpha = 0$$

$$V = \frac{\pi DN}{60} = \frac{\pi \times 400 \times 0.16}{60}$$

$$V = 3.35 \text{ m/s}$$

$$F_R = F_T \sin \psi$$

$$F_F = F_T \cos \psi$$

$$\psi = 90^\circ - 75^\circ = 15^\circ$$

$$800 = F_T \cos 15^\circ$$

$$F_T = 828.22 \text{ N}$$

$$F = F_T \cos \alpha + F_C \sin \alpha$$

$$F = 828.22 \text{ N}$$

$$N = F_C \cos \alpha - F_T \sin \alpha$$

$$N = 1200 \text{ N}$$

$\Rightarrow$

2.

$$\frac{F_S}{\left(\frac{w \cdot t_1}{\sin \phi}\right)} = \tau_s$$

$$\tan \phi = \frac{\cos \alpha}{\frac{t_2}{t_1} - \sin \alpha}$$

$$\text{As } \alpha = 0 \text{ then } \tan \phi = \frac{t_1}{t_2}$$

$$t_1 = f \cos \psi = 0.31 \text{ mm}$$

$$w = \frac{d}{\cos \psi} = 4.14 \text{ mm}$$

$$\tan \phi = \frac{0.31}{0.8}$$

$\Rightarrow$

$$\phi = 21.18^\circ$$

$$F_S = F_C \cos \phi - F_T \sin \phi$$

$$F_S = 1200 \cos 21.18^\circ - 828.22 \sin 21.18^\circ$$

$$F_S = 819.7 \text{ N}$$

$$\tau_s = \frac{819.7 \sin 21.18^\circ}{0.31 \times 4.14}$$

$$\tau_s = 230.76 \text{ MPa}$$

3.

$$P_C = F_C V$$

$$P_C = 1200 \times 3.35$$

$$P_C = 4020 \text{ W}$$

Example : 4.5

While machining steel with zero rake angle prove the following expression where τ_s is shear strength of material P_c is specific cutting power and r is chip reduction coefficient (t_1/t_2)

$$\frac{\tau_s}{P_c} = \frac{r(1-\mu r)}{1+r^2}$$

Solution :

P_c = Specific cutting power

$$P_c = \frac{F_c}{w.t_1}$$

$$r = \frac{t_1}{t_2}$$

If sufficient data is not provided assume $\alpha = 0$

$$\frac{F_s}{\left(\frac{w.t_1}{\sin \phi}\right)} = \tau_s$$

$$\frac{\tau_s}{P_c} = \frac{F_s}{F_c} \sin \phi$$

$$\frac{F_s}{F_c} = \frac{\cos(\phi + \beta - \alpha)}{\cos(\beta - \alpha)}$$

$$\frac{\tau_s}{P_c} = \frac{\cos(\phi + \beta - \alpha)}{\cos(\beta - \alpha)} \sin \phi$$

As

$$\alpha = 0$$

$$\frac{(\cos \phi \cos \beta - \sin \phi \sin \beta)}{\cos \beta} \sin \phi$$

$$= (\cos \phi - \sin \phi \tan \beta) \sin \phi$$

$$= \cos \phi \sin \phi - \mu \sin^2 \phi$$

$$r = \tan \phi = \frac{\cos \alpha}{\frac{1}{r} - \sin \alpha}$$

$$\Rightarrow \frac{\sin \phi}{\cos \phi} = r$$

$$\Rightarrow \sin^2 \phi + \cos^2 \phi = 1$$

$$\Rightarrow \tan^2 \phi + 1 = \frac{1}{\cos^2 \phi} = 1 + r^2$$

$$\cos \phi = \frac{1}{\sqrt{1+r^2}}$$

$$\Rightarrow \sin \phi = \frac{r}{\sqrt{1+r^2}}$$

$$\Rightarrow \frac{\tau_s}{P_c} = \left(\frac{1}{\sqrt{1+r^2}} - \frac{r}{\sqrt{1+r^2}} \mu \right) \frac{r}{\sqrt{1+r^2}}$$

$$\Rightarrow \frac{r}{1+r^2} - \frac{r^2}{1+r^2} \mu$$

$$\Rightarrow \frac{\tau_s}{P_c} = \frac{r(1-\mu r)}{1+r^2}$$

Example 4.6

During orthogonal machining with an HSS Tool, the rake angle was 5° , the undeformed chip thickness was 0.25 mm and width of cut was 4 mm. Assuming shear strength of work material to be 350 N/mm² and coefficient of friction to be 0.5, estimate cutting and thrust force.

Solution :

$$\alpha = 5^\circ, t_1 = 0.25 \text{ mm}, w = 4 \text{ mm}, \tau_s = 350 \text{ N/mm}^2, \mu = 0.5$$

$$\text{Friction angle, } \beta = \tan^{-1}(\mu) = \tan^{-1}(0.5) = 26.565^\circ$$

$\therefore$ Merchant condition for minimum power consumption

$$2\phi + \beta - \alpha = 90$$

$$2\phi + 26.565 - 5 = 90$$

$$2\phi = 68.435^\circ$$

$$\text{Shear Angle, } \phi = 34.22^\circ$$

$$\text{Shear force, } F_s = \frac{\tau_s \cdot w \cdot t_1}{\sin \phi} = \frac{350 \times 4 \times 0.25}{\sin 34.22} = 622.4 \text{ N}$$

$$\therefore F_s = R \cos(\beta - \alpha + \phi)$$

$$\therefore R = \frac{F_s}{\cos(\beta - \alpha + \phi)}$$

$$\therefore \text{Cutting force, } F_c = R \cos(\beta - \alpha)$$

$$= \frac{F_s \cos(\beta - \alpha)}{\cos(\beta - \alpha + \phi)}$$

$$= \frac{622.4 \cos(26.565 - 5)}{\cos(26.565 - 5 + 34.22)} = 1029.4 \text{ N}$$

$$\text{Thrust force, } F_T = \frac{F_s \sin(\beta - \alpha)}{\cos(\beta - \alpha + \phi)}$$

$$= \frac{622.4 \sin(26.565 - 5)}{\cos(26.565 - 5 + 34.22)} = 406.8 \text{ N}$$

Example : 4.7

Mild steel is being machined at a cutting speed of 200 m/min with a tool rake angle of 10° . The width of cut and uncut chip thickness are 2 mm and 0.2 mm respectively. If the avg. value of coefficient of friction between the tool and chip is 0.5 and shear strength of work material is 400 N/mm^2 . Determine

- (i) Shear angle.
- (ii) Cutting and thrust components of the machining forces.

Solution :

Cutting speed, $V_c = 200 \text{ m/min}$, $\alpha = 10^\circ$, $w = 2 \text{ mm}$, $t_1 = 0.2 \text{ mm}$, $\mu = 0.5$, $\tau_s = 400 \text{ N/mm}^2$

Friction angle, $\beta = \tan^{-1}(\mu) = \tan^{-1}(0.5)$

$$\beta = 26.565^\circ$$

We know that for metal cutting, Lee-shaffer condition

$$\phi + \beta - \alpha = 45^\circ$$

$$\phi + 26.565 - 10 = 45^\circ$$

$$\phi = 28.435^\circ$$

... shear angle

Shear force

$$F_s = \frac{\tau_s \cdot w \cdot t_1}{\sin \phi}$$

$$= \frac{400 \times 2 \times 0.2}{\sin(28.435)} = 336.02 \text{ N}$$

$$\therefore F_s = R \cdot \cos(\phi + \beta - \alpha)$$

$$\therefore R = \frac{336.02}{\cos(28.435 + 26.565 - 10)} = 475.204 \text{ N}$$

where R is resultant force of

- (i) Cutting force & thrust force or
- (ii) Normal & friction force at tool chip interface.

$\therefore$ Cutting force

$$F_c = R \cos(\beta - \alpha)$$

$$= 475.2 \times \cos(26.565 - 10) = 455.48 \text{ N}$$

Thrust force

$$F_T = R \sin(\beta - \alpha)$$

$$= 475.2 \sin(26.565 - 10) = 135.48 \text{ N}$$

Example : 4.8

Following data from the orthogonal cutting test is available rake angle $\alpha = 10^\circ$, chip thickness ratio $r = 0.35$, uncut chip thickness $t_1 = 0.51 \text{ mm}$, width of cut $w = 3 \text{ mm}$, yield shear stress of work material = 285 N/mm^2 . Coefficient of friction at tool-chip interface = 0.65. Determine

1. Cutting force.
2. Thrust force.
3. Normal force on tool chip interface.
4. Shear force on tool.

Solution :

1. Cutting force
- ∴ Shear angle, ϕ

$$\tan \phi = \frac{r \cos \alpha}{1 - r \sin \alpha}$$

$$= \frac{0.35 \cos 10}{1 - 0.35 \sin 10} = 0.367$$

$$\phi = 20.15^\circ$$

$$\text{Friction angle, } \beta = \tan^{-1}(\mu) = \tan^{-1}(0.65)$$

$$\beta = 33.024^\circ$$

$$\text{Shear force, } F_s = \frac{\tau_s \cdot w \cdot t_1}{\sin \phi}$$

$$= \frac{285 \times 3 \times 0.51}{\sin(20.15^\circ)} = 1265.8 \text{ N}$$

$$\therefore (\beta + \phi - \alpha) = 33.024 + 20.15 - 10 = 43.174^\circ$$

∴ Net force on the tool

$$R = \frac{F_s}{\cos(\beta + \phi - \alpha)}$$

$$= \frac{1265.8}{\cos(43.174)} = 1735.7 \text{ N}$$

∴ Cutting force

$$F_c = R \cos(\beta - \alpha)$$

$$= 1735.7 \times \cos(33.024 - 10) = 1597.4 \text{ N}$$

Thrust force

$$F_T = R \sin(\beta - \alpha)$$

$$= 1735.7 \times \sin(23.024) = 679.3 \text{ N}$$

Normal force on tool

$$N = R \cos \beta$$

$$= 1735.7 \cos(33.024) = 1455.3 \text{ N}$$

Shear force on the tool

$$F_s = 1265.8 \text{ N}$$

Example : 4.9

A seamless tube 32 mm outer diameter is turned on the lathe the cutting velocity of tool relative to workpiece is 10 m/min. Rake angle, $\alpha = 35^\circ$, depth of cut, $t_1 = 0.125$ mm, length of chip = 60 mm. Horizontal cutting force of the tool on workpiece = 200 N vertical cutting force required to hold the tool against work = 80 N. Calculate

1. Coefficient of friction
2. Chip thickness ratio.
3. Shear plane angle.
4. Velocity of chip relative to tool.
5. Velocity of chip relative to workpiece.

Solution :

$$V = 10 \text{ m/min}, \alpha = 35^\circ, l_c = 60 \text{ mm}$$

Assuming no expansion along width

$$\therefore t_1 \cdot \pi D = l_c \cdot t_2$$

$$\frac{t_1}{t_2} = r\text{-chip thickness ratio} = \frac{l_c}{\pi D}$$

$$\therefore r = \frac{60}{\pi \times 32} = 0.597$$

$$F_c = 200 \text{ N}, F_T = 80 \text{ N}$$

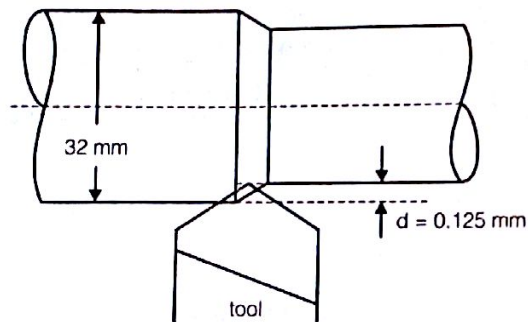


Fig. 4.22

1. Coefficient of friction

$$\begin{aligned} \mu &= \frac{F_T + F_c \tan \alpha}{F_c - F_T \tan \alpha} = \frac{80 + 200 \tan 35}{200 - 80 \tan 35} \\ &= \frac{220.04}{143.98} = 1.5282 \end{aligned}$$

2. Chip thickness ratio $r = 0.597$

3. Shear plane angle (ϕ)

$$\tan \phi = \frac{r \cos \alpha}{1 - r \sin \alpha} = \frac{0.597 \cos 35}{1 - 0.597 \sin 35}$$

$$\phi = 36.64^\circ$$

4. Velocity of chip relative to tool

$$\begin{aligned} V_c &= r \cdot V = 0.597 \times 10 \\ &= 5.97 \text{ m/min} \end{aligned}$$

5. Velocity of chip relative to workpiece

$$\begin{aligned} V_s &= \frac{V \cos \alpha}{\cos (\phi - \alpha)} = \frac{10 \cos 35}{\cos (36.64 - 35)} \\ &= 8.195 \text{ m/min} \end{aligned}$$

4.15 CONTACT LENGTH

After machining as the chips flow over the rake face, the temperature of material will be very high. At high temperature coefficient of friction increases and hence shear stress. Once the shear stress reaches yield strength of shear, sticking will take place between the materials. So over the rake face initially there will be sticking and there is slipping.

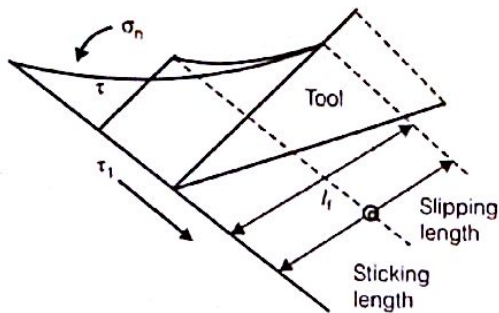


Fig. 4.23 (a)

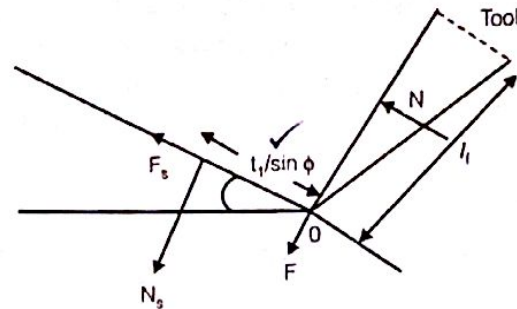


Fig. 4.23 (b)

Taking moments about O in Fig. 4.23 (b)

$$\Rightarrow N_s \times \frac{1}{2} \frac{t_1}{\sin \phi} = N \times \frac{1}{2} l_t$$

$$\Rightarrow N_s \times \frac{t_1}{\sin \phi} = N l_t$$

$$N_s = R \sin (\phi + \beta - \alpha)$$

$$N = R \cos \beta$$

$$\Rightarrow R \sin (\phi + \beta - \alpha) \frac{t_1}{\sin \phi} = R l_t \cos \beta$$

So contact length l_t is

$$\Rightarrow l_t = t_1 \frac{\sin (\phi + \beta - \alpha)}{\sin \phi \cos \beta}$$

4.16 MEASUREMENT OF TEMPERATURE

4.16.1 Tool work piece thermocouple

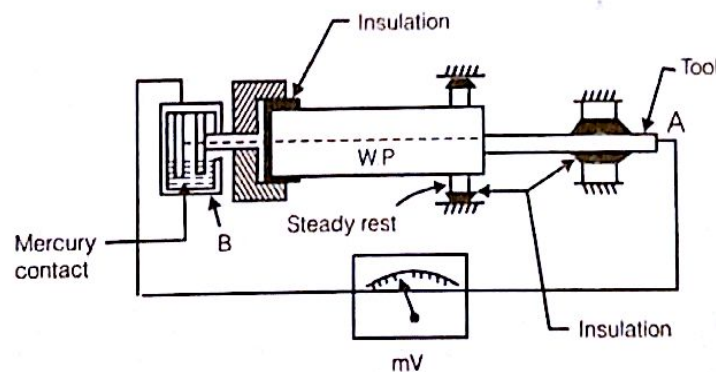


Fig. 4.24 (a)

It is based on the principle of Seebeck effect that is when a combination of materials is kept at a temperature gradient there will be a flow of current which will be proportional to the temperature difference. Tool work piece junction acts as a hot junction point and mercury bath serves as a cold junction point. Mercury bath is also provided to have a metal contact. If there is a build up edge formation of oxide layer measured temperatures are not accurate.

4.16.2 Inserted thermocouple

A hole is drilled from the back side of the tool and a thermocouple is inserted into it. Although the temperature measurements are unaffected by build up edge or oxide layer formation over the tool, but it has to be calibrated before use.

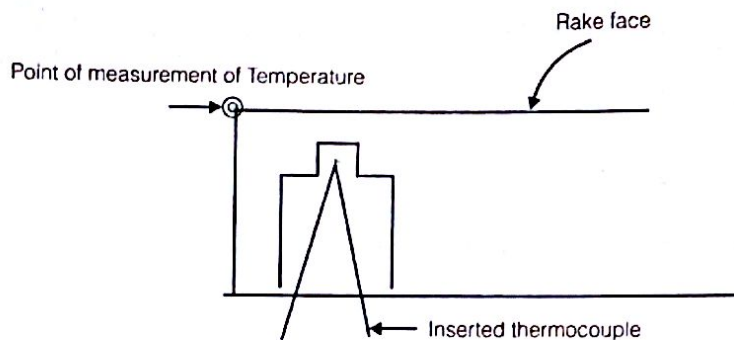


Fig. 4.24 (b)

4.16.3 Infrared measurement

The infrared radiation from the cutting zone may also be monitored with a radiation pyrometer or probes. These probes are very expensive. However the technique indicates only surface temperatures. Depending on the temperatures certain wave length radiations will come out from the machining area and the radiations are captured by probes. The accuracy of the results depends on the emissivity of the surfaces, which is difficult to determine accuracy.

4.16.4 Hardness and microstructure studies

Samples of known steel composition are inserted over the rake face. After machining, hardness and microstructure of the specimens are tested. By analysing the microstructure it is evaluated that what was the temperature over the rake face.

4.17 CUTTING FLUIDS ✓

Cutting fluids are used for decreasing power requirement and increasing heat dissipation. The main factors likely to cause excessive heat during metal cutting are

- Cutting speed is too high.
- Poor surface finish on the cutting face of the tool.
- Worn or incorrectly ground cutting tool.
- Formation of a built up edge on cutting face of the tool.
- Friction between tool and work piece.

There are three zones at which heat is generated they are Shear zone, Friction zone and Tool work piece zone. Cutting fluids generally used are:

1. Neat oils + Extreme pressure additives (EP additives)
2. Water emulsions

EP (Extreme Pressure) additives like Chlorine, Sulphur, and Phosphorus are added into Neat oils. Since Manganese is present in the material in the form of impurity EP additives react with the manganese and produce low shear strength film. This decreases the power consumption in machining operation. When the cutting speeds are higher, there will not be any time for the reaction to take place, so water emulsions are used to decrease the viscosity of the cutting fluid so that it takes away heat from the machining area.

4.17.1 Properties of cutting fluids

1. Higher conductivity
2. Low viscosity
3. It should not react with machining components
4. Easily available
5. It should not fume
6. It should not foam
7. It should not give bad odour.

4.17.2 Selection of cutting fluids

We can apply cutting fluids in two ways.

- Mist application
- Flood application

In mist application cutting fluids come out in the form of spray and penetrates into the machining area which increases the probability of reaction. But at higher speeds Flood applications are used.

Cutting speeds :	Low speeds	:	Neat oils + EP additives.
	Medium speeds	:	1 : 10 water emulsion + EP additives
	High speeds	:	1 : 100 water emulsions.

4.17.3 Work piece material

1. **Cast iron (CI) :** While machining cast iron cutting fluids are not used because, it produces graphite flakes, this mixes with the cutting fluid and affects the machining area. So, either no cutting fluid is used or compressed air is used.
2. **Steel :** For low cutting speeds cutting fluids used are Neat oil and EP additives. For medium cutting speeds cutting fluids used are water emulsions in the ratio 1:10. For high cutting speeds cutting fluids used are water emulsions in the ratio 1:100.
3. **Aluminium :** Cutting fluids used are Neat oil and EP additives (Kerosene with EP additives) Aluminium is a very soft material so, at a high speed nothing is required, but at low speed, there will be a tendency of build up edge formation, so neat oils with EP additives are used.
4. **Magnesium :** Magnesium reacts with water at high temperature and burns, so only neat oils are used.
5. **Brass and Bronze :** EP additives present in the cutting fluid reacts with the material and produces dull surface. So, only Neat oils like kerosene is used.

4.18 MECHANISM OF TOOL WEAR

1. **Diffusion wear** : The favourable condition for the diffusion is provided by the localized temperature over the actual area between the chip underside and the tool face. In that condition the metal atoms will transfer from the tool material to the chip material at the points of contact. This weakens the surface structure of the cutting tool and may ultimately lead to tool failure. The amount of diffusion depends upon temperature, period of contact between tool face and the chip and the bonding affinity between the materials of the tool and chip.

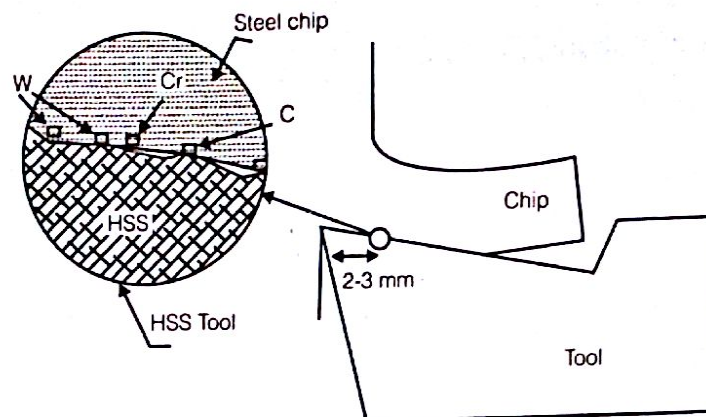


Fig. 4.25 (a) : Schematic diagram of Diffusion wear

2. **Adhesion wear** : Due to the excessively high temperature at the chip-tool interface a metallic bond takes place between the chip material and tool material at the contact points, in the form of spot welds are formed. When the chip slides, these small welds are broken and small amount of welded tool carried away by the sliding chip. Thus small particles will continue to separate through this phenomenon and carried away by the chip by adhesion to its underside.

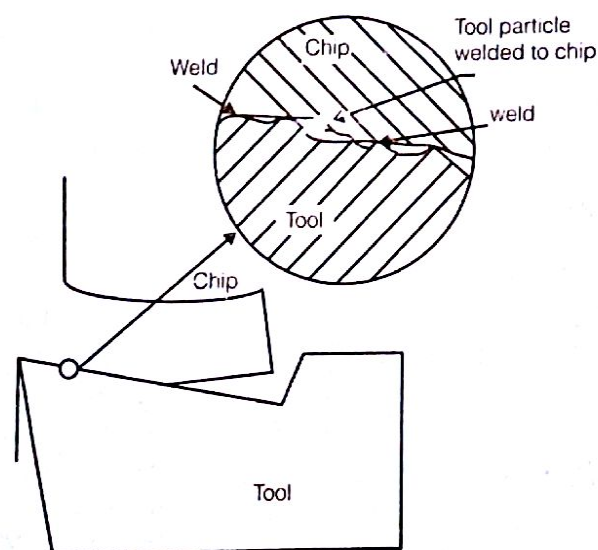


Fig. 4.25 (b) : Schematic diagram of Adhesion wear

3. **Abrasion wear** : Since there will be thousands of faylite pockets inside the work material and as these faylite pockets come in contact with the cutting edge, there will be a shock. As a result of that, a portion of cutting edge will be eroded.

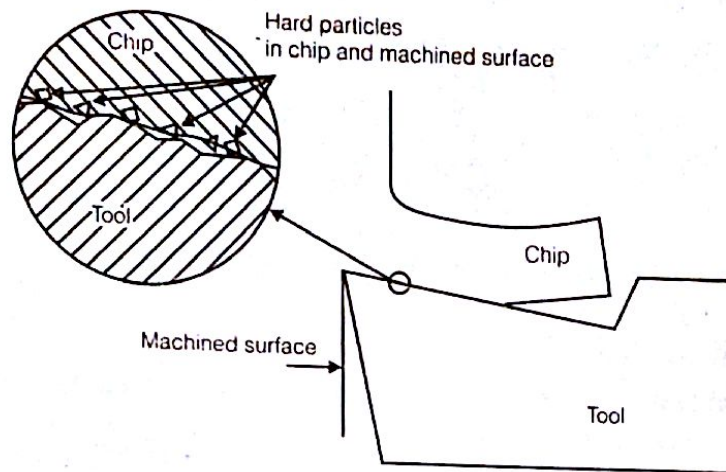


Fig. 4.25 (c) : Schematic diagram of Abrasion wear

4. **Fatigue wear** : On a microscopic level, hills of the tool will be eroded and fresh hills will be formed by the interaction with the work piece. This eroded material is called fatigue wear.

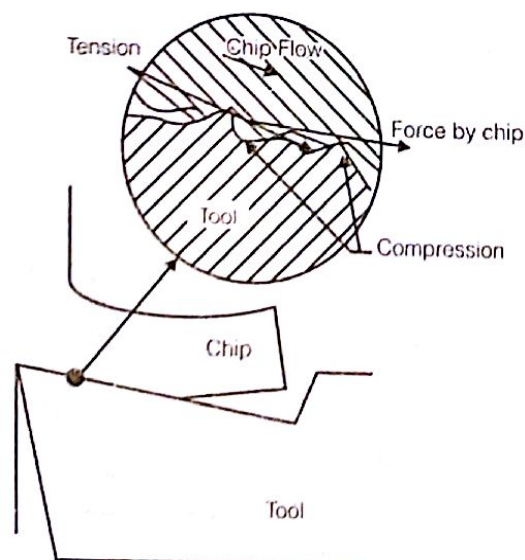


Fig. 4.25 (d) : Schematic diagram of Fatigue wear

5. **Oxidation wear** : After machining operation, oxide layer will be formed over the tool which will be removed in the next cut. The formation of grooves or notches at the rake face and the flank is on account of the sliding of portions of the chip and the machined surface which have reacted with the oxygen in the atmosphere to form abrasive oxides. This causes oxidation wear.

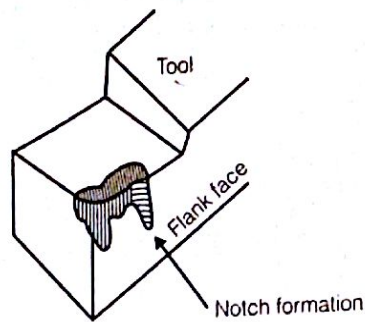


Fig. 4.25 (e) : Schematic diagram of Oxidation wear

4.18.1 Types of Tool Wear

1. **Flank wear** : Flank wear is more at the corner and notch because:
 - (a) There is sudden entry and sudden exit at the corner and at the notch.
 - (b) There is also a work hardening of the material in the width direction.
 A stage reaches when diffusion becomes the predominant wear mode on the flank. After a critical wear land has formed, further wear takes place at an accelerating rate. It is advisable to change the tool in order to avoid the tool failure. Flank wear is caused mainly through abrasion, whereas during the rapid wear phase it is caused by diffusion.
2. **Crater wear** : Crater wear is mainly due to the diffusion and abrasion between the chip and the face of the tool, a short distance from the cutting edge. The crater is formed on the surface of the tool by the action of chip particles flowing over it because of very high temperature. When crater becomes excessive, the cutting edge may break from the tool. This is generally observed while machining ductile materials, which produces continuous chips.

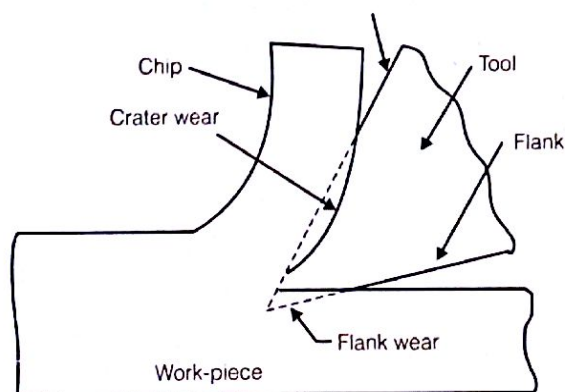


Fig. 4.26 (a) : Schematic diagram of Flank wear and Crater wear

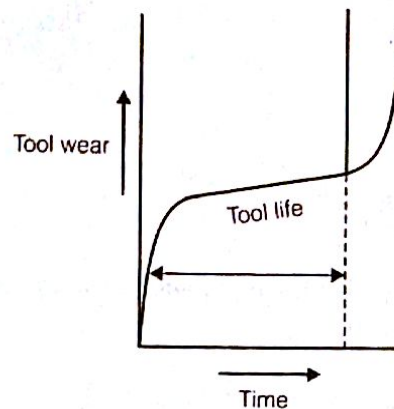


Fig. 4.26 (b) : Variation of tool wear with respect to time

$V_B = 0.3$, it is the depth of Flank wear.

$K_T = 0.3$, it is the depth of crater wear.

Initially, the cutting edge is sharp and as soon as it comes in contact with the work piece, sharp edges try to round off. That is why; the tool wear is more in the beginning. After some amount of tool wear takes place, tool loses its geometry and causes the drag between the tool and the work piece increases. This results in tool breakdown. Before this condition comes, tool has to be withdrawn from the work shop and reground. This time between two regrindings is called **TOOL LIFE**.

4.18.2 TAYLOR'S TOOL LIFE EQUATION

The tool life is mainly affected by cutting speed, means higher the cutting speed the smaller the tool life. Taylor gave the relation between cutting speed and tool life that is

$$VT^n = C$$

V = cutting speed

T = tool life.

C = machining constant.

n = Tool life exponent (depends only on tool material)

For HSS,	$n = 0.08 - 0.2$
For carbides	$n = 0.2 - 0.6$
For ceramics	$n = 0.5 - 0.8$

C depends upon both tool and work piece.

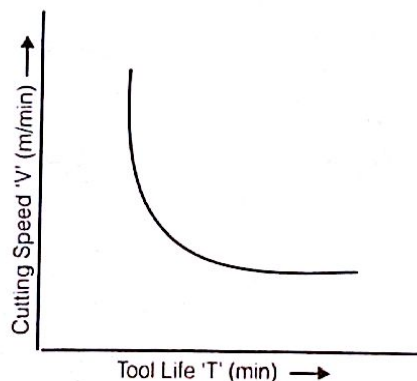


Fig. 4.27 : Variation of velocity with respect to time

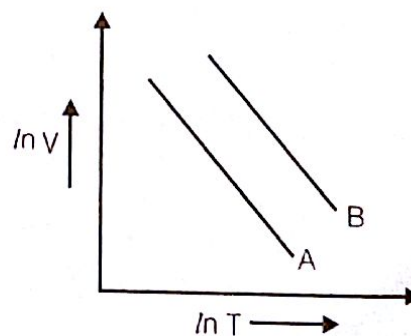


Fig. 4.28 : Two curves having same slope

Hyperbola

$$VT^n = C$$

$$\log V + n \log T = \log C$$

As the two lines are parallel slope (n) is same for both. B makes higher intercept on the axis, 'C' for B is higher than that for A.

Example : 4.10

Following is the data available on cutting speed and tool life.

$$V = 150 \text{ m/min} \quad T = 60 \text{ min}$$

$$V = 200 \text{ m/min} \quad T = 23 \text{ min}$$

Determine the Taylors constant and tool life exponent.

Solution :

$$VT^n = C$$

$$150(60)^n = C$$

$$200(23)^n = C$$

$$\Rightarrow 150(60)^n = 200(23)^n$$

$$\Rightarrow \left(\frac{60}{23}\right)^n = \frac{200}{150}$$

$$\Rightarrow (2.6087)^n = 1.33$$

$$\Rightarrow n \log (2.6087) = \log 1.33$$

$$\Rightarrow n = 0.3$$

$$C = 512.31$$

Example : 4.11

Spindle speed (N)	Feed (f)	Components
250	0.1	311
250	0.125	249
300	0.125	144

This is the record of number of identical components produced at different speeds and feeds. Estimate the number of components that can be produced at a spindle speed of 350 rpm and feed of 0.15 mm/rev

Solution :

$$N^a C_1^b = C$$

$$250(0.1)^a (311)^b = C$$

$$\ln 250 + a \ln 0.1 + b \ln 311 = \ln C \quad \dots(1)$$

$$\ln 250 + a \ln 0.125 + b \ln 249 = \ln C \quad \dots(2)$$

$$\ln 300 + a \ln 0.125 + b \ln 144 = \ln C \quad \dots(3)$$

Solving (1) and (2)

$$a (\ln 0.1 - \ln 0.125) + b (\ln 311 - \ln 249) = 0$$

$$\Rightarrow -0.223 a + 0.2223 b = 0$$

$$\Rightarrow 0.223 a = 0.2223 b$$

Solving (2) and (3)

$$(\ln 250 - \ln 300) + b (\ln 249 - \ln 144) = 0$$

$$\begin{aligned}
 b &= 0.333 \\
 a &= 0.3318 \\
 C &= 787.46 \\
 \text{So } 350 (0.15)^{0.3318} C_1^{0.333} &= 787.46 \\
 C_1^{0.333} &= 4.222 \\
 \log C_1 &= 4.3253 \\
 C_1 &= 75.59
 \end{aligned}$$

✓ So

So 75 components will be produced.

Example : 4.12

In drilling of 20 mm diameter hole in a M.S. solid block of 25 mm thickness, the feed rate used is 0.25 mm/rev. The drill must be changed after making 10 holes if it is rotated at 250 rpm. But the drill can produce 50 holes if it is rotated at 200 rpm. How many holes can be produced if its rpm is 150?

Solution :

Time to drill 10 holes at 250 rpm

$$T_1 = \frac{10 \times 25}{0.25 \times 250} = \frac{1000}{250} = 4 \text{ minutes}$$

Time to drill 50 holes at 200 rpm

$$T_2 = \frac{50 \times 25}{0.25 \times 200} = \frac{50 \times 25 \times 100}{25 \times 200}$$

$$T_2 = 25 \text{ minutes}$$

Taylor Tool life equation

$$T_1^n N_1 = T_2^n N_2 = C$$

Taking logarithmic of both sides

$$n \ln T_1 + \ln N_1 = n \ln T_2 + \ln N_2$$

$$n = \frac{(\ln N_1 - \ln N_2)}{(\ln T_2 - \ln T_1)}$$

$$n = \frac{\ln 250 - \ln 200}{\ln 25 - \ln 4}$$

$$= \frac{0.22314}{1.8326} = 0.1218$$

Tool life at $N_3 = 150$ rpm

$$\begin{aligned}
 \therefore T_1^n N_1 &= T_3^n N_3 \\
 4^{0.1218} \times 250 &= T_3^{0.1218} \times 150
 \end{aligned}$$

$$T_3 = 4 \times \left(\frac{250}{150} \right)^{\frac{1}{0.1218}}$$

$$= 265.142 \text{ minutes}$$

Time to drill a hole

$$T_1 = \frac{25}{0.25} \times \frac{1}{150} = \frac{100}{150} \text{ min}$$

$$V = \frac{FDM}{60} \dots (1)$$

log ✓

$$\begin{aligned}
 \text{No. of holes} &= \frac{T_3}{T_1} \\
 &= \frac{265.143}{100} \times 150 \\
 &= 397.7145 = 398 \text{ holes}
 \end{aligned}$$

Example : 4.13

A carbide tool with MS workpiece was found to give tool life of 2 hrs while cutting at 0.5 m/min. Compute the tool life if the same tool is used at speed of 25% higher than previous one. Also determine the value of cutting speed if the tool is required to have tool life of 3 hrs. Assume Taylor's exponent 'n' to be 0.27?

Solution :

Taylor's Tool life

$VT^n = C$, where V-m/min, T-minutes

$n = 0.27$ -Taylor's exponent

at $V_1 = 0.5$ m/min, $T = 2$ hrs = 120 min

$$\therefore 0.5 \times (120)^{0.27} = c$$

$$\therefore c = 1.82116$$

Now the speed is 25% higher

$$\therefore V_2 = 1.25 \times 0.5 = 0.625 \text{ m/s}$$

$$\therefore V_2 T_2^{0.27} = 1.82116$$

$$0.625 \cdot T_2^{0.27} = 1.82116$$

$$T_2 = 52.51 \text{ min}$$

Again the tool life, $T_3 = 3$ hrs = 180 min

$$\therefore V_3 T_3^{0.27} = 1.82116$$

$$V_3 = \frac{1.82116}{(180)^{0.27}}$$

$$V_3 = 0.44815 \text{ m/min}$$

Example : 4.14

In a drilling operation under a given condition, the tool life found to decrease from 20 min to 5 min, due to increase in drilling speed from 200 rpm to 400 rpm. What will be the tool life of that drill under the same condition if the drill speed is 300 rpm.

Solution

$$\therefore T_1 = 20 \text{ min at } N_1 = 200 \text{ rpm}$$

$$T_2 = 5 \text{ min at } N_2 = 400 \text{ rpm}$$

But Taylor's tool life equation for drill

$$N_1 T_1^n = N_2 T_2^n = \text{constant}$$

... (1)

$$\therefore 200(20)^n = 400(5)^n$$

$$4^n = 2$$

$$\therefore n = 0.5$$

$$\therefore \text{Tool life at } N_3 = 300 \text{ rpm}$$

∴

$$N_1 T_1^n = N_2 T_2^n$$

$$200(20)^{0.5} = 300 T_3^{0.5}$$

$$T_3 = 20 \left(\frac{200}{300} \right)^2 = 8.89 \text{ min}$$

Example : 4.15

A generalized Taylor's tool life equation was obtained for HSS tool;

$$V = \frac{C}{T^{0.13} f^{0.6} d^{0.3}}$$

A 60 min tool life was obtained using the following cutting parameters, $V = 40 \text{ m/min}$, $f = 0.25 \text{ mm}$, $d = 2.00 \text{ mm}$. Compute the tool life if cutting speed, feed and depth of cut are increased by 25% and also if they are increased individually by 25% where V -cutting speed, f = feed, d = depth of cut.

Solution :

$$\therefore V = \frac{C}{T^{0.13} f^{0.6} d^{0.3}}$$

$$\therefore T = \frac{C^{\frac{1}{0.13}}}{V^{\frac{1}{0.13}} f^{\frac{0.6}{0.13}} d^{\frac{0.3}{0.13}}}$$

$$T = \frac{C^{7.7}}{V^{7.7} f^{4.6} d^{2.3}} \quad \dots (1)$$

This expression shown that tool life depend upon speed most, then feed and then least on depth of cut.

$$\therefore 60 = \frac{C^{7.7}}{40^{7.7} (0.25)^{4.6} (2)^{2.3}}$$

$$C = 36.5 \text{ units}$$

Now new set of parameter

$$V' = 1.25 \times 40 = 50 \text{ m/min}$$

$$f' = 1.25 \times 0.25 = 0.3125 \text{ mm}$$

$$d' = 1.25 \times 2 = 2.5 \text{ mm}$$

$$\therefore T' = \frac{(36.5)^{7.7}}{(50)^{7.7} (0.3125)^{4.6} (2.5)^{2.3}}$$

$$= 2.27 \text{ minutes}$$

Now speed increased

$$= \left(\frac{40}{50} \right)^{7.7} \times 60 = 10.76 \text{ min}$$

Now feed is increased

$$= \left(\frac{0.25}{0.3125} \right)^{4.6} \times 60 = 21.5 \text{ min}$$

Now depth of cut is increased

$$\begin{aligned} \therefore T_d' &= 60 \times (0.8)^{2.3} \\ &= 36 \text{ min} \end{aligned}$$

Hence decreasing order of effect of various parameters on tool life are
speed $\rightarrow$ feed $\rightarrow$ depth of cut.

Example : 4.16

A turning tool with sharp corner and a major cutting edge angle of 60° is to be used at a feed of 0.05 mm. What minor cutting edge angle should be provided to obtain an arithmetical mean surface roughness of $3 \mu\text{m}$. under ideal condition?

Solution :

ψ major cutting edge angle = 60

ψ_1 minor cutting edge angle = ?

$\therefore$ Maximum height of roughness

$$\therefore H_{\max} = \frac{f}{(\tan \psi + \cot \psi_1)} \quad \dots (1)$$

$$R_a = \frac{H_{\max}}{4}$$

Given that

$$f = 0.05 \text{ mm}$$

$$R_a = 3 \times 10^{-3} \text{ mm}$$

So

$$R_a = \frac{f}{4(\tan \psi + \cot \psi_1)}$$

$$3 \times 10^{-3} = \frac{0.05}{4(\tan \psi + \cot \psi_1)}$$

$$\tan \psi + \cot \psi_1 = \frac{50}{4 \times 3} = 4.1667$$

$$\tan 60 + \cot \psi_1 = 4.1667$$

$$\cot \psi_1 = 4.1667 - 1.732$$

$$= 2.4316$$

$$\tan \psi_1 = 0.41074 = 22.33^\circ$$

4.19 EFFECT OF PARAMETERS ON TOOL LIFE

1. **Cutting Speed :** Higher the cutting speed more will be the temperature over the rake face and faylite pockets will create more impact over the cutting edge. So tool life will decrease.

2. **Feed and Depth of cut :** By increasing the feed and depth of cut, tool life will decrease because it increases the cutting forces.

The empirical formulae is given by

$$V = \frac{257}{T^{0.19} f^{0.36} t^{0.8}}$$

V = cutting speed in m/min

T = tool life in min

f = feed rate in mm/min

t = depth of cut in mm

For a given tool life the relationship among other variables is also given by the following empirical formulae

$$V = \frac{C}{f^a t^b}$$

V = cutting speed for given tool life

C = constant.

The exponents a and b depends on the mechanical properties of the material.

3. **Size and Structure :** When the work piece has fine grain structure, tool life will decrease and when the tool material has fine grain structure, tool life will increase.
4. By increasing the intermittent cuts tool life decreases.

4.20 MACHINABILITY

The ease with which a given material may be worked with a cutting tool is Machinability. Factors affect the Machinability are :

1. **Tool life :** The longer the tool life it enables at a given cutting speed better is the Machinability
2. **Surface finish :** Two materials are machined under identical cutting conditions and material which produces good finish is considered to be more machinable material. This criterion is used in finished cuts.
3. **Cutting Forces :** Two materials are machined under identical cutting conditions and the material which requires smaller cutting forces is considered to be more machinable. This criterion is used in smaller and old machines.

Machinability index :

V_s = Cutting speed of standard free-cutting steel for 1 min tool life.

V_t = Cutting speed of metal for 1 min tool life.

Standard work piece material is machined at a cutting speed so that tool life 'T' is observed.

Keeping other parameters same, test work piece is machined to get the same tool life 'T'.

Machinability index indicates that the material is more machinable.

$$\text{Machinability index} = \frac{V_t}{V_s} \times 100$$

Table : Representative Machinability Indexes for some material

Material	Machinability index
Stainless steel	25
Low carbon steel	55-65
Copper	70
Red brass	180
Aluminium alloys	300 - 1500
Magnesium alloys	500 - 2000
C-45 (0.45%C)	100
Mn steel	60
Free cutting steels	200
C-14 (0.14%C)	160

4.21 ECONOMICS OF MACHINING

To achieve the object in metal cutting such as optimizing the tool life in order to minimize the production cost, maximizing the production rate to reduce the production cost etc. optimum cutting speed must be selected. For Example if cutting speed reduced in order to enhance the tool life the metal removal rate is also reduced and, therefore the production cost increases similarly to the increase in the tool life by reducing the feed rate and depth of cut. If metal removal rate is increased which increases the cutting speed and depth of cut, the tool life shortens and therefore tooling cost increases and so total production cost increases. So a balance is therefore required to get optimum cutting speed which ensures economical production.

As seen in figure 4.29 it is observed that the tooling cost increases while the machining cost decreases with increase in cutting speed. Also there is a point 'p' on the total cost curve which indicates the minimum cost of production. The cutting speed corresponding to this point gives the optimum cutting speed for economical production.

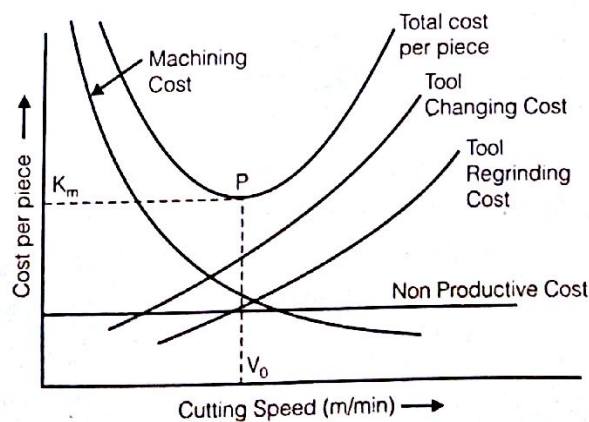


Fig. 4.29 (a) : Effect of variations in cutting speed on various cost factors

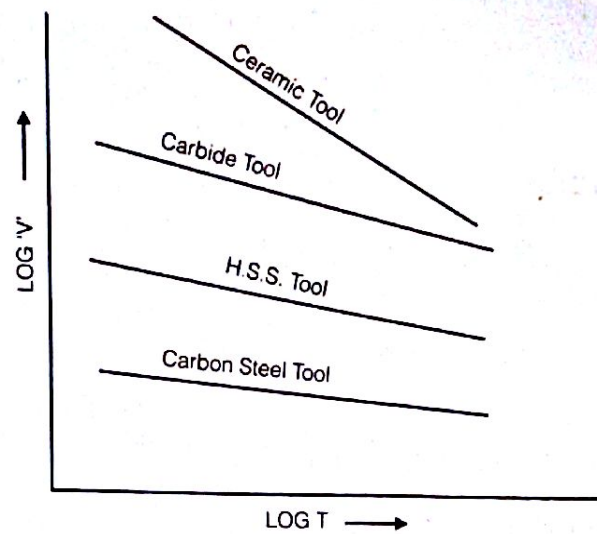


Fig. 4.29 (b) Variation of velocity with respect to time for different materials

C_m = Machine cost in Rs/time

T_m = Machining time

$$T_m = \frac{l}{fN}$$

l = total length of cut

f = feed

N = rpm

$V = \pi DN$

$$N = \frac{V}{\pi D}$$

⇒

$$T_m = \frac{\pi D l}{f V}$$

1. Machining cost

$$C_1 = C_m \cdot T_m$$

$$C_1 = C_m \cdot \frac{\pi D l}{f V} \quad \dots(1)$$

2. Idle cost

$$C_2 = C_m \times T_h$$

T_h = idle time/component

...(2)

3. Tool cost

C_e = Cost/regrind

C_e = Tool material cost + Grinding cost

$$C_3 = C_e \times \frac{T_m}{T}$$

$$VT^n = C$$

$$\frac{1}{T} = \left(\frac{V}{C} \right)^{\frac{1}{n}}$$

$$C_3 = C_e \times \left(\frac{\pi D l}{fV} \right) \left(\frac{V}{C} \right)^{\frac{1}{n}} \quad \dots(3)$$

4. Tool Changing Cost

$$C_4 = C_m \times \left(\frac{T_m}{T} \right) \times T_c$$

T_c = tool changing time

$$C_4 = C_m \cdot \left(\frac{\pi D l}{fV} \right) \times \left(\frac{V}{C} \right)^{\frac{1}{n}} \times T_c \quad \dots(4)$$

The total cost can be found by adding the four costs.

$$C = C_1 + C_2 + C_3 + C_4$$

1. For total minimum cost

$$\frac{dC}{dV} = \frac{dC_1}{dV} + \frac{dC_2}{dV} + \frac{dC_3}{dV} + \frac{dC_4}{dV}$$

$$= \frac{d}{dV} \left(C_m \times \frac{\pi D l}{fV} \right) + \frac{d}{dV} (C_m \times T_n) + \frac{d}{dV} \left(C_e \times \frac{\pi D l}{fV} \left(\frac{V}{C} \right)^{\frac{1}{n}} \right) + \frac{d}{dV} \left(C_m \times \frac{\pi D l}{fV} \times \left(\frac{V}{C} \right)^{\frac{1}{n}} \times T_c \right) = 0$$

$$\frac{-C_m \pi D l}{fV^2} + \frac{d}{dV} \left(\frac{C_e \pi D l}{fC^{1/n}} \times \left(\frac{V}{C} \right)^{\frac{1}{n}-1} \right) + \frac{d}{dV} \left(C_m \times \frac{\pi D l}{fC^{1/n}} T_c V^{\frac{1}{n}-1} \right) = 0$$

By Differentiating

$$\Rightarrow \frac{\pi D l}{f} \left(\frac{-C_m}{V^2} + \frac{C_e}{C^{1/n}} \left(\frac{1-n}{n} \right) V^{\frac{1}{n}-2} + \frac{C_m}{C^{1/n}} T_c \left(\frac{1-n}{n} \right) V^{\frac{1}{n}-2} \right) = 0$$

$$\Rightarrow \frac{-C_m}{V^2} + \frac{C_e}{C^{1/n}} \left(\frac{1-n}{n} \right) V^{\frac{1-2n}{n}} + \frac{C_m}{C^{1/n}} T_c \left(\frac{1-n}{n} \right) V^{\frac{1-2n}{n}} = 0$$

$$\Rightarrow \frac{-C_m}{V^2} + \frac{C_e}{C^{1/n}} \left(\frac{1-n}{n} \right) \times \frac{1}{V^{\frac{2n-1}{n}}} + \frac{C_m}{C^{1/n}} T_c \left(\frac{1-n}{n} \right) \times \frac{1}{V^{\frac{2n-1}{n}}} = 0$$

$$\Rightarrow \left(-C_m + \frac{C_e}{C^{1/n}} \left(\frac{1-n}{n} \right) \times \frac{1}{V^{-1/n}} + \frac{C_m}{C^{1/n}} T_c \left(\frac{1-n}{n} \right) \times \frac{1}{V^{\frac{-1}{n}}} \right) = 0$$

$$= C_m = \frac{1}{V^{-1/n}} \left(\frac{1-n}{n} \right) \frac{1}{C^{1/n}} (C_e + T_c C_m)$$

$$= V^{-1/n} = \left(\frac{1-n}{n} \right) \frac{1}{C^{1/n} C_m} (C_e + T_c C_m)$$

$$= V^{1/n} = \frac{n}{1-n} \frac{C^{1/n} C_m}{(C_e + T_c C_m)}$$

$$V = \left[\frac{n}{1-n} \frac{C^{1/n} C_m}{(C_e + T_c C_m)} \right]^n$$

$$V_{opt} = \frac{C}{\left[\left(\frac{C_e}{C_m} + T_c \right) \left(\frac{1}{n} - 1 \right) \right]^n}$$

$$T_{opt} = \left[\left(\frac{C_e}{C_m} + T_c \right) \left(\frac{1}{n} - 1 \right) \right]$$

2. For maximum production rate

Time taken for 1 product

$$T = T_m + T_h + \frac{T_m}{T} T_c$$

No of products per unit time

$$R_p = \frac{1}{T}$$

$$T = \frac{\pi D l}{f V} + T_h + \left(\frac{\pi D l}{f V} \right) \left(\frac{V}{C} \right)^{1/n} T_c$$

$$\frac{dT}{dV} = 0$$

$$\Rightarrow \frac{-\pi D l}{f V^2} + \frac{\pi D l}{f C^{1/n}} V^{\frac{1}{n}-1-1} \left(\frac{1}{n} - 1 \right) T_c = 0$$

$$\Rightarrow \frac{\pi D l}{f} \left[\frac{-1}{V^2} + \frac{1}{C^{1/n}} V^{\frac{1}{n}-2} \left(\frac{1}{n} - 1 \right) T_c \right] = 0$$

$$\Rightarrow \frac{1}{V^2} = \frac{1}{C^{1/n}} V^{\frac{1}{n}-2} \left(\frac{1}{n} - 1 \right) T_c$$

$$\Rightarrow V^{\frac{1}{n}-2+2} = \frac{C^{1/n}}{\left(\frac{1}{n} - 1 \right) T_c}$$

$$\Rightarrow V^n = \frac{C^{1/n}}{\left(\frac{1}{n}-1\right)T_c}$$

$$\Rightarrow V_{opt} = \frac{C}{\left[\left(\frac{1}{n}-1\right)T_c\right]^n}$$

$$\Rightarrow T_{opt} = \left(\frac{1}{n}-1\right)T_c$$

3. For maximum profit rate

$$\text{Profit rate} = \frac{R - C_0}{T_m + T_h + \frac{T_m}{T} \times T_c}$$

R = selling price

(V_{opt}) production rate > (V_{opt}) profit rate > (V_{opt}) minimum unit cost

When V is increased beyond max productivity, tool life decreases. Frequent grinding is required when cutting speed increases and hence productivity decreases.

Example : 4.17

The results of machining steel with two grades of tool are given below

Tool	Taylor's experiment	Cutting speed for 1 min tool life, m/min
A	0.20	100
B	0.25	120

For a 180 min tool life which tool is recommended and why ?

Solution :

For

$$A \rightarrow VT^{0.2} = 100$$

$$B \rightarrow VT^{0.25} = 120$$

1. If tool life = 180 min

$$V_A = \frac{100}{180^{0.2}} = 35.39 \text{ m/min}$$

$$V_B = \frac{120}{180^{0.25}} = 32.76 \text{ m/min}$$

Tool A : as $V_A > V_B \Rightarrow$ higher speed leads to higher productivity

2. If the tool grinding and changing time is 15min which cutting speeds for tool A has to be chosen from two available speeds 45 m/min and 50 m/min?

$$T_c = 15 \text{ min}$$

Calculation of optimum cutting speed for maximum productivity.

$$V_{opt} = \frac{C}{\left[\left(\frac{1}{n}-1\right)T_c\right]^n}$$

$$\Rightarrow = \frac{100}{\left[\left(\frac{1}{0.2} - 1\right)^{15}\right]^{0.2}}$$

$$\Rightarrow = 44.093 \text{ m/min}$$

45 m/min has to be chosen

Example 4.18

In a cutting operation with a cutting speed 50 m/min tool life of 45 min was observed. When the cutting speed was increased to 100 m/min tool life decreases to 10 min. Estimate the cutting for maximum productivity if tool changing time is 2 min?

Solution :

	V	T
	50 m/min	45 min
	100 m/min	10 min
(V _{opt}) max productivity,		T _C = 2 min
		VT ⁿ = C
⇒		(50)(45) ⁿ = C
⇒		(100)(10) ⁿ = C
⇒		(50)(45) ⁿ = (100)(10) ⁿ
		= n /n 45 = /n 2 + 1/n /n 10
		= n [/n 45 - /n 10] = /n 2
		= n = 0.46
		C = 50 (45) ^{0.46}
		C = 100 (10) ^{0.46}
		C = 288.036

$$V_{\text{opt}} = \frac{C}{\left[\left(\frac{1}{n} - 1\right) T_C\right]^n}$$

$$= \frac{288.036}{\left[\left(\frac{1}{0.46} - 1\right) 2\right]^{0.46}}$$

$$\Rightarrow = \frac{288.036}{\left[\left(\frac{1}{0.46} - 1\right) 2\right]^{0.46}}$$

$$\Rightarrow V_{\text{opt}} = 194.51 \text{ m/min}$$

Example : 4.19

A cylindrical bar is to be turned. The max. allowable feed is 0.2 mm per revolution and at this feed rate Taylor's tool life equation is $VT^{0.25} = 75$ where V is cutting speed m/min and T is tool life in minutes. The labour cost and overheads is Rs 8/- per minute and regrinding cost is Rs 120/-. On an average it takes about 2 minutes to change the tool. Estimate cutting speed for minimum cost.

Solution

Total cost = Machining cost + tool changing cost + tool regrinding cost

C = Machining time × labour cost + changing time × labour cost + regrinding cost × time

$$= \frac{\pi D}{1000 v} \times \frac{L}{f} C_1 + t_{cl} \times \frac{\pi D}{1000 v} \times \frac{L}{f} \times \frac{1}{T_{\text{tool life}}} \times C_1 + C_2 \frac{\pi D}{1000 f} \cdot \frac{L}{V} \times \frac{1}{T_{\text{tool life}}}$$

$$C = \frac{\pi DL}{1000 f} \left[\frac{C_1}{V} + \frac{t_{ct}}{V} C_1 \left(\frac{V}{75} \right)^{\frac{1}{0.25}} + \frac{C_2}{V} \left(\frac{V}{75} \right)^{\frac{1}{0.25}} \right]$$

$$= \frac{\pi DL}{1000 f} \left[\frac{C_1}{V} + \frac{C_1 t_{ct} V^3}{75^4} + \frac{C_2 V^3}{75^4} \right] \quad \dots (1)$$

where C_1 is labour cost = Rs. 8.0 per min, C_2 is tool regrinding cost = Rs. 120

For minimum cost

$$\left(\frac{dC}{dV} \right) = 0 = \left[-\frac{C_1}{V^2} + \frac{3 C_1 t_{ct} V^2}{75^4} + \frac{3 C_2 V^2}{75^4} \right]$$

$$\frac{C_1 \times 75^4}{(3 C_1 t_{ct} + 3 C_2)} = V^4$$

$$V = 75 \left(\frac{C_1}{3 C_1 t_{ct} + 3 C_2} \right)^{1/4}$$

$$= 75 \left(\frac{8}{3 \times 8 \times 2 + 3 \times 120} \right)^{0.25}$$

$$= 75 \times 0.3742$$

$$V = 28.065 \text{ m/s}$$

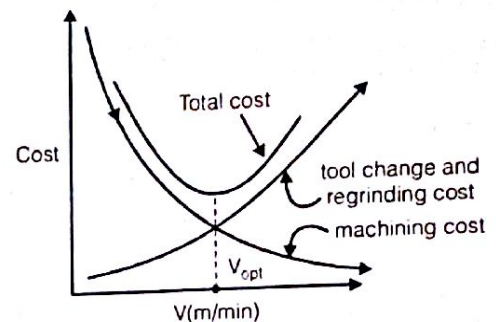


Fig. 4.30 : Graphical representation of various cost

4.22 TOOL MATERIALS

Properties of cutting tool materials

1. **High hot hardness or Red hardness** : It is the property of the material by which it retains hardness at elevated temperatures.
2. **Toughness** : Toughness gives the material, ability to absorb shock.
3. **High thermal conductivity** : To dissipate heat.
4. Low coefficient of friction, at the chip- tool interface, the surface finish is good and wear is minimum.
5. Low coefficient of expansion.

Following are important tool materials:

1. **High carbon steel** : Hardness 750 HV (Vickers Hardness), at cutting speed of 5-6 m/min, and as cutting speed increases its hardness will come down to 150 HV. It is primarily used in wood working.
2. **High Speed Steel** : Normal cutting speed by this tool material is 28 – 30 m/min and its hardness is 850 HV.
18% W + 4% Cr + 1% V (18 – 4 – 1 HSS) was the initial material developed in this category but at present HSS is broadly classified into T-series (W major alloying element) and M-series (MO major impurity). Some of the important material in HSS are:

T-series Symbol	Percentage			
	W	Cr	V	CO
T - 1	18	4	1	0
T - 4	18	4	1	5
T - 7	14	4	2	0
T6 (Super HSS)	20	4	2	12

In M-series the most important material is M-2 and its compositions are 0.8% C, 4% Cr, 2% V, 6% W and 5% Mo.

3. Cemented Carbides : Following are the hardness of allowing elements of these tools :

Tungsten Carbide (WC) 2000 HV,

Titanium Carbide (TiC) 3100 HV,

Tantalum Carbide (TaC) 1800 HV.

- P-type : 30%TiC + 60%(WC + TaC) toughest + 10%Co
- M- type: 15% TiC + 75%(WC + TaC) toughest + 10%Co
- K-type: 90% (WC + TaC) + 10% Co

Powder Technology is used for preparing Carbide chips. These carbide inserts cannot be reground, hence called throw away inserts. Carbide tools are fixed over the tool bit by brazing (in industries) or by fastening (in work shops). Only the carbide chip is made by powder metallurgy technique and it is fixed over the tool bit by brazing operation. Once one cutting edge wears out, carbide chip is removed and again fixed in such a way that other cutting edge comes into action. Once all the cutting edges wear out, carbide chips are discarded. That is why it is called Throw away inserts. Maximum Cutting Speed achieved by these materials is 150 m/min.

4. UCON : This is Niobium based alloy developed by union carbide company. UCON consists of 50% columbium 30 % titanium and 20 % tungsten. These are produced by rolling process. Nitrogen is finally diffused into the surface at a temperature of 650°C to produce a hard surface layer. These are used for machining steel at high speeds and feeds. It is not suitable for cast iron and stainless steel.

5. Cast Hard Alloys : These are produced by casting process. These alloys retain their hardness up to temperatures as high as 800-900°C and have low coefficient of friction. This is especially used for making form tools. UCON and cast hard alloys are inferior to carbides and superior to high speed steel. Cobalt (Co) is used as binding agent.

6. Ceramic : Sintered or powdered metallurgically produced (Aluminium oxide) tools which are superior to carbide attached to tool bit by brazing. They have less tendency to adhere to metals during cutting. So, lower tendencies to form a built up edge. Ceramic tool tips are highly brittle so they are usually attached to the shank by means of epoxy resins. Cutting Speed is 400m/min can be achieved by these tools and its hardness is 2200 HV.

7. Sialon (Si-Al-O-N) : It is a recently developed tool material which produces excellent surface finish over the material, but it is costly. This is produced by milling silicon nitride, aluminium nitride, alumina, yttrium oxide. It has higher thermal shock resistance than silicon nitride and is tougher than aluminium. It is recommended for machining cast irons and nickel based super alloys at intermediate cutting speeds, because of chemical affinity to iron this is not suitable for machining steels. Cutting speed is 300 m/min.

8. **CBN (Cubic Boron Nitride)** : Hardness value is 4700 HV and cutting speed is 600-700 m/min can be achieved by CBN. Boron has Hexagonal structure but when it is heated under certain pressure it converts into cubic, which is a very hard structure. Generally, it is used as an abrasive in grinding wheel. CBN coated tools are used primarily to machine stainless steel and high speed steel. The tool life of CBN is excellent for machining quenched alloy steel for dies.
9. **Diamond** : Its hardness value is 7500 HV. Cutting speed is 1000m/min. Diamond dust is used as an abrasive in grinding wheel. It is harder than any other material and has high thermal conductivity.
10. **Coated Tools** : Coating of HSS cutting tools with thin layers of about 2- 15 m of a refractory metal carbide or nitride like TiC, TiN, TiCN and TiAlN. Coating is done by two methods.
 - Physical Vapor Deposition
 - Chemical Vapor Deposition

4.23 MEASUREMENT OF CUTTING FORCES

Dynamometers : In metal cutting operation the device used for determination of cutting forces is known as tool Dynamometer.

Types of dynamometer:

1. Mechanical Dynamometers.
2. Strain gauge type Dynamometers.
3. Pneumatic and Hydraulic Dynamometers.
4. Electrical Dynamometers.
5. Piezoelectric Dynamometers.

Mechanical Dynamometers are simple type dynamometer, which uses the sensitive dial indicators for directly measuring the tool forces. The dial indicators are calibrated to show readings directly.

Strain Gauge Dynamometer : Strain gauges are mounted on a plate and when the load is applied on the plate, the length of those strain gauges will change. This will in turn change the resistance. Strain gauges are connected to the wheat stone bridge and the change in resistance is recorded by the flow of current. When the strain gauges are bounded with another plate, although such strain gauges will not be affected by the change in environment but the maintenance of such gauges becomes difficult.

4.24 GRINDING

Grinding process is used as a finishing process to get the desired surface finish, correct size and accurate shape of the product.

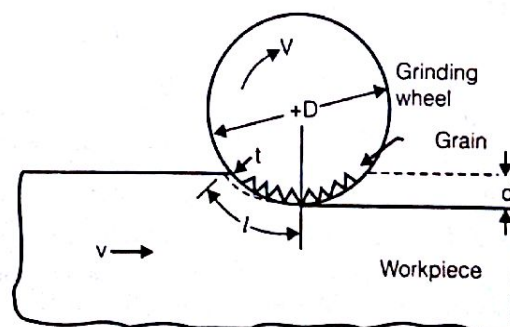


Fig. 4.31 : Grinding Operation

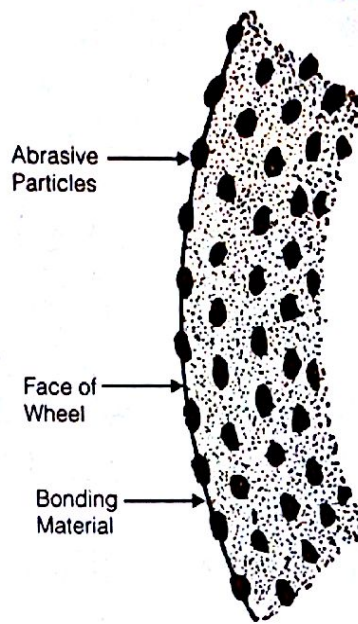


Fig. 4.32 : Cutting Action of Grinding Wheel

Grinding wheel consists of abrasive particles, bonding material and voids. The projecting abrasive particles act like cutting tool tips and remove metal. A properly selected grinding wheel exhibits self sharpening action. As cutting proceeds the abrasive particles, at cutting edge become dulled, and eventually these becomes plane and which resists the cutting action. Thus new cutting edge points are produced which carry out the further cutting action. This process continues till the abrasive grains get worn down till the level of bond. At this position new cutting edges will do further cutting action.

The rate at which grinding wheel enters into the work piece is called In Feed. The in-feed process is used for stepped cylindrical work pieces which cannot be through-feed. And the feed with which, grinding wheel moves along the surface of work is called Through Feed. In High Speed Grinding, infeeds are low and the grinding wheel is not supposed to remove more material. It is meant for super finishing operation. In Creep Feed Grinding, infeeds are high and speeds are low. It is meant for bulk metal removal.

4.24.1 Classification of Grinding Processes

1. **Surface grinding** : Used for grinding flat surfaces.
2. **Cylindrical grinding** : This is used for grinding external and internal cylindrical surfaces.
3. **Center-less grinding** : It is used for grinding of external and internal surfaces. In this, machines are different from that of cylindrical grinding.
4. **Form grinding** : It is used for grinding of gears, thread grinding and grinding of splines etc.
5. **Abrasive cut off** : This is used for severing metallic and non metallic materials.
6. **Abrasive belt grinding** : It is used for grinding flat, cylindrical, or curved shapes.
7. **Manual grinding** : it is used in processes those in which work piece or grinding wheel is held by hand.
8. **Creep feed grinding** : it is a method in which a soft grinding wheel is used. In this large amount of metal is removed in a single pass.

Some grinding processes are shown below:

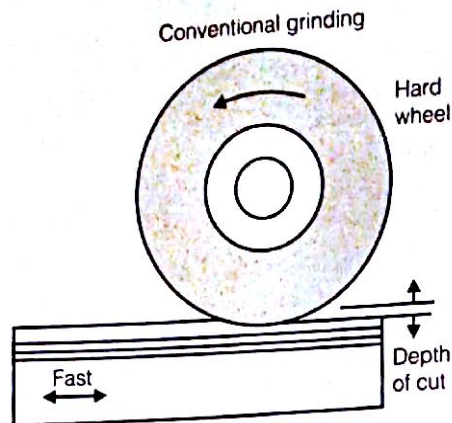


Fig. 4.33 (a) : Surface Grinding

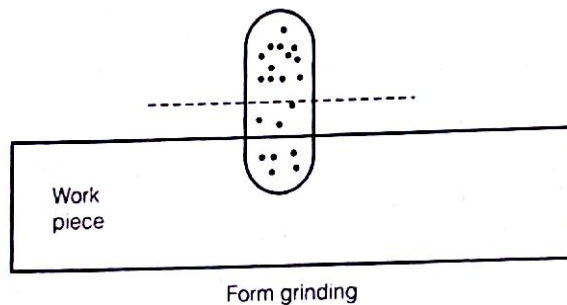


Fig. 4.33 (b) : Form Grinding

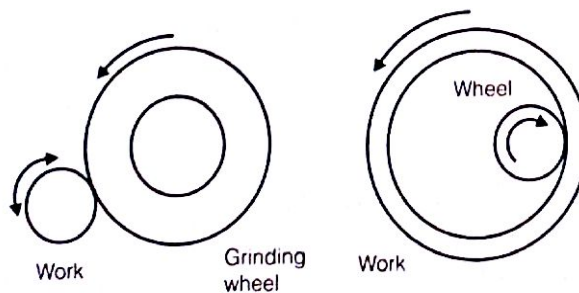


Fig. 4.33 (c) : Internal grinding and external grinding.

Center-less Grinding : Work piece which are smaller in sizes, very fragile or non symmetric can be grinded by this process. Work pieces are kept slightly above the common axis of grinding and the regulating wheel. Regulating wheel is given an inclination so that one component of force provides infeed and the other component provides through feed. As a result of that, work piece will automatically move from the surface of grinding wheel and come out from the other side. Speed of the regulating wheel = $1/20$ of the grinding wheel.

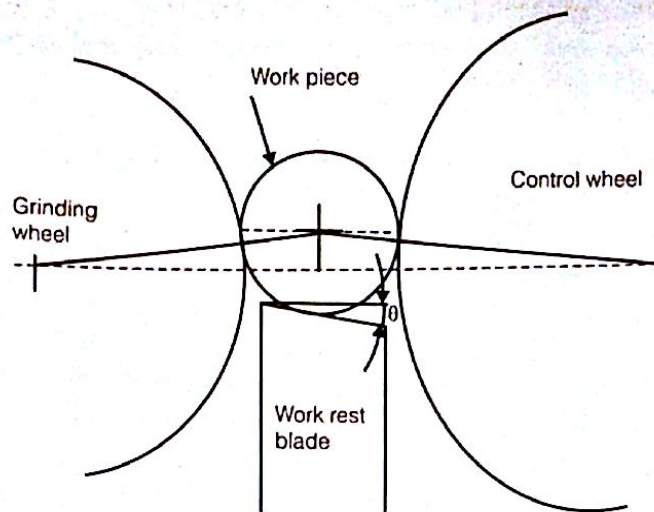


Fig. 4.34 : Center-less through feed grinding.

There are three processes in center-less grinding.

1. Through feed
2. Infeed
3. End feed.

In through feed grinding the work piece is supported and revolved, simultaneously axial movement is given by regulating wheel and guides so as to pass between the wheels. In Infeed grinding both regulating and grinding wheels are more in width than the work length to be ground. Axis of regulating wheel is inclined a little, about half a degree from the horizontal. This is used for grinding, shouldered or formed components. In this the work rest does not carry guides.

In End feed grinding the both wheels, grinding wheel and the regulating wheel are dressed to contain the required shape or form. The work piece is fed longitudinally from the sides of the wheels. As it advances between the revolving wheels its surface is ground till its farther end touches the end stop.

4.24.2 Structure

Structure is the distance between the two cutting edges.

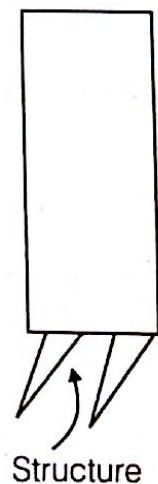
Open structure : The proportion of the bond in a certain volume of the wheel affects the structure.

- In open structure space is more.
- It is used in ductile materials.
- Continuous chips of ductile materials can be accommodated and thrown out of centrifugal action.

Close structure :

- It occupies less space.
- It is used for brittle and hard materials.

And open structures are used for ductile materials so that long chips goes into the space between the abrasives. When the surface of the wheel which is not in contact with the work pieces, these chips will go away from the space by centrifugal action. When ductile materials are machined with close structure, chips will be forced to enter into the space which is not sufficient. This produces



Structure

Fig. 4.35

welding between the abrasives. When such process continues, all the voids will be blocked, and wheel will rub over the work piece without any cutting this phenomenon is called loading.

4.24.3 Grade

Grade or hardness indicates the strength, with which the bonding materials holds the abrasive grains in the grinding wheel.

Sharp grains after coming in contact with the work piece become blunt which increases the drag between the abrasive grain and the work piece. If the bonding agent is weak, abrasive grain will be pulled from the wheel and the fresh grain from the back ground will start cutting action. This phenomenon is called self sharpening characteristic. The wheels which have predominating self sharpening characteristics are called Soft Wheels and if the bonding agent is strong such wheels are Hard Wheels. For machining soft materials hard wheels are used and vice versa. If hard materials are machined by hard wheels, gradually all the grains will wear out on the surface of wheel and wheel starts rubbing over the work piece without cutting. This phenomenon is called glazing.

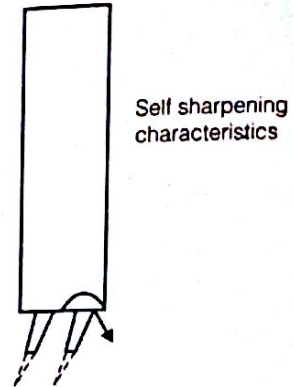


Fig. 4.36

Depth of cut: It is the thickness of metal removed by the grinding wheel in one traverse stroke.

$$t = \text{Depth of cut}$$

$$\text{depth of cut} = \frac{D_1 - D_2}{2}$$

D_1 = Diameter of work piece before grinding

D_2 = Diameter of work piece after grinding

Feed:

In cylindrical grinding feed is the longitudinal movement of the work piece per revolution.

f = feed in mm per work piece revolution

$$= K_1 B$$

B = Face width of wheel in mm

= constant

= 0.4 to 0.6 for finish grinding

= 0.6 to 0.9 for rough grinding.

$$\text{Work travel} = \frac{f \times n}{1000} \text{ m/min}$$

4.24.4 ISO Designation of Grinding Wheel

① ② ③ ④ ⑤
51 - C - 30 - M - 5 - V - 20

First and last number : Manufacturer has to give special information about the grinding wheel. According to this system the various elements and characteristics of grinding wheel are represented on all the wheels in a definite sequence as follows.

1. Type of abrasive
 - C - carbide
 - A - Aluminium oxide (Al_2O_3)
 - D - Diamond
2. Grain size
 - 10 - 24 roughening
 - 30 - 60 Medium

- 70 - 180 Finishing
 - 220 - 600 Superfinishing operation
- Per square inch opening in the mesh. These are number of opening per square inch area.
3. Hardness
 - A - H soft wheels
 - I - P medium wheels
 - Q - Z hard wheels
 4. Structure
 - 0 - dense
 - 16 - open
 5. Type of bond
 - V - Vitrified bond (glass material which produces strong wheel)
 - S - Silicate
 - B - Resinoid (Thermosetting materials which are flexible than vitrified bond)
 - R - Rubber (Most flexible bond material)
 - M - Metal bond

4.24.5 Wheel Dressing

Wheel wear ratio = Work piece material/Wheel material lost
 As soon as new grinding wheel comes in contact with the work, sharp grains become blunt, that is why wheel wear will be more in the beginning. After certain period of time, due to glazing or loading, there is a surface contact between the wheel and work piece, large piece of grinding wheel will start coming out causing break down. Before this situation comes wheel has to be withdrawn from the work shop and dressed. Dressing is a procedure to remove a layer of abrasive from the surface of grinding wheel. This time between the two dressings is called wheel life. Due to dressing, wheel may lose its cylindricity and the process of making it cylinder again is called Wheel Truing.

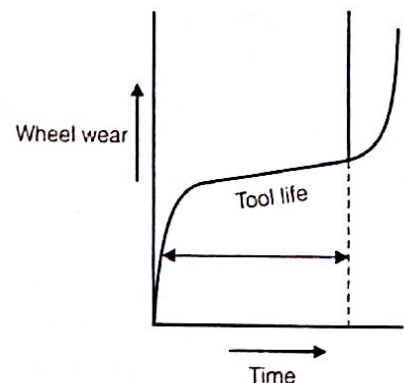


Fig. 4.37 : Variation of wheel wear with respect to time

4.25 UNCONVENTIONAL/NON-TRADITIONAL MACHINING PROCESSES

4.25.1 Electro Chemical Machining

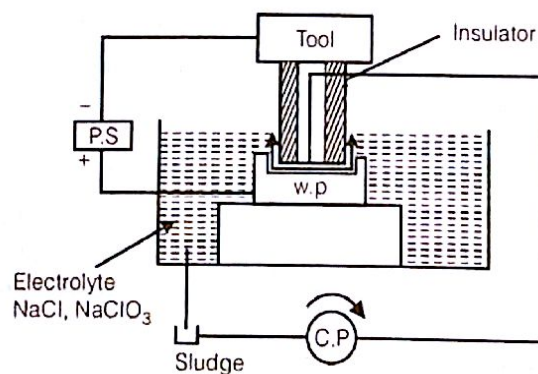


Fig. 4.38 (a) : Machining using Electro chemical machining

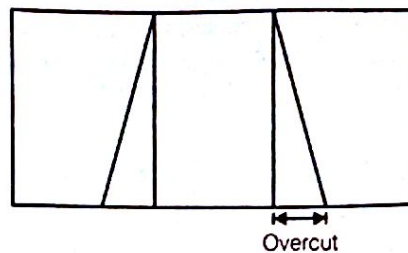
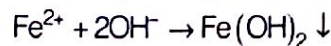
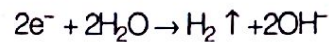
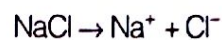
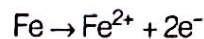


Fig. 4.38 (b) : Showing Over Cut

Tool Material used : Brass, Bronze, Copper, Aluminium.

Gap between electrode and work piece : 0.03 – 0.5 mm

Centre line average value (R_a) 0.2 – 0.8 μ 's



In ECM process, material removal takes place atom by atom, that is, reverse of electrolysis. This is high current, low voltage process. Material removal is proportional to the current settings and the temperature of electrolyte. The electrolyte temperature has to be controlled very precisely because even increase in temperature 5°C produces over cut of 0.2 mm. Electrolyte which is conducting in nature is supplied within the machining area through a hole in the tool. Insulation is provided on the side of the tool so that reaction doesn't take place side ways making the hole tapered. The process produces excellent surface finish and there is no wear of tool and it has main applications in machining steam turbine blades and die sinking. Since, hydrogen gas is produced during the reaction, so there has to be a safe passage for its removal because it can explode under its own weight. Although ECM installations are very expensive but its operational cost is very low and economics is justified by the quality product it produces.

Mass of material removal $\propto$ charge

$$\text{Mass} \propto q \propto I t$$

$$\text{Mass} = Z I t$$

$$Z = \frac{e}{F}$$

Z = Electrochemical Equivalent

F = Faraday's constant = 96500

e = Chemical equivalent (Atomic weight/valency)

I = Current passed (Amp)

t = time (seconds)

$$\text{Metal Removal Rate (MRR)} = \frac{eI}{F\rho} = sI \text{ (cm}^3\text{/sec)}$$

ρ = density (gm/cm³)

$$s = \text{Specific material removal rate (MRR)} = \frac{e}{F\rho}$$

$$\text{Electrode feed rate} = s \times S_1$$

$$S_1 = \text{Current density} = \frac{I}{A}$$

$$I = \frac{\Delta V}{R}$$

$$R = \rho_s \frac{l}{A}$$

ρ_s = electrical resistivity

$$S_1 = \frac{\Delta V}{\rho_s I}$$

l = Gap between tool and workpiece.

Example : 4.20

Calculate the MRR and electrode feed rate when copper is electrochemically machined Under following conditions.

$$\rho_s = 5 \Omega \text{ cm}$$

$$\Delta V = 18 \text{ V}$$

$$I = 500 \text{ A}$$

$$\text{Tool gap} = 0.5 \text{ mm}$$

$$\text{Atomic Weight} = 56$$

$$\text{Valency} = 2$$

$$\rho = 7.8 \text{ g/cm}^3$$

Solution :

$$\text{MRR} = s I$$

$$s = \frac{e}{F \rho}$$

$$e = \text{Atomic weight/valency}$$

$$= 56/2 = 28$$

$$F = 96500$$

$$s = \frac{28}{96500 \times 7.8} = 3.72 \times 10^{-5}$$

$$\text{MRR} = s I = 0.0186 \text{ cm}^3/\text{s}$$

$$\text{Electrode feed rate} = s \times S_1$$

$$S_1 = \text{Current density} = \frac{I}{A} = \frac{\Delta V}{RA} = \frac{\Delta V}{\rho_s l}$$

$$= \frac{18}{5 \times 0.05} = 0.134 = 72 \text{ Amp/m}^2$$

$$\text{Feed rate} = 3.72 \times 10^{-5} \times 72 \text{ cm/s}$$

$$= 2.67 \times 10^{-3} \text{ cm/s} = 0.0267 \text{ mm/s}$$

Example : 4.21

A researcher conducts electrochemical machining (ECM) on a binary alloy (density 6000 kg/m^3) of iron (atomic weight 56, valency 2) and metal P (atomic weight 24, valency 4). Faraday's constant = 96500 coulomb/mole. Volumetric material removal rate of the alloy is $50 \text{ mm}^3/\text{s}$ at a current of 2000 A. What is the percentage of the metal P in the alloy.

Solution :

The equivalent, chemical equivalent is

$$\frac{1}{e} = \frac{4}{24} \times \left(\frac{x}{100} \right) + \left(\frac{100-x}{100} \right) \times \frac{2}{56}$$

where the percentage of P in alloy is x.

The MRR in ECM process can be represented by

$$\text{MRR} = \frac{eI}{F_p}$$

but putting the values, $50 = \frac{e \times 2000}{96500 \times 6000 \times 10^{-6}}$

$$e = 14.475$$

putting this value in previous expression we get

$$x = 25.482\%$$

Example : 4.22

Electrochemical machining is performed to remove material from an iron surface of 20 mm × 20 mm under the following conditions:

Inter electrode gap = 0.2 mm

Supply voltage (DC) = 12 V

Specific resistance of electrolyte = 0.2 Ω mm

Atomic weight of Iron = 55.85

Valency of Iron = 2

Faraday's constant = 96540 Coulombs

What is the material removal rate (in gm/s).

Solution :

$$R = \rho_s \frac{I}{A}$$

$$V = IR$$

$$\text{MRR} = \frac{eI}{F_p} \text{ m}^3/\text{s}$$

$$R = 2 \times 10^{-1} \times \frac{0.2}{20 \times 20} \Omega$$

$$R = 10^{-4} \Omega$$

$$12 = I \times 10^{-4}$$

$$I = 12 \times 10^4 \text{ A}$$

$$e = \frac{55.85}{2} = 27.925$$

$$\text{MRR} = \frac{27.925 \times 12 \times 10^4}{96500}$$

$$= 34.725 \text{ gm/s}$$

Example : 4.23

Evaluate MRR of a Nimonic alloy {Co - Ni - Cr}

	%	Atomic Weight	Valency
Co	18	58.93	2
Ni	62	58.71	2
Cr	20	51.99	6

$$I = 500 \text{ A} \quad \rho = 8.28 \text{ gm/cm}^3$$

Solution :

$$\frac{1}{e} = \frac{\sum \% \times \text{valence}}{\text{atomic weight}}$$

$$\Rightarrow \frac{0.18 \times 2}{58.93} + \frac{0.62 \times 2}{58.71} + \frac{0.2 \times 6}{51.99}$$

$$\Rightarrow \frac{1}{e} = 0.050311$$

$$\text{MRR} = \text{SI}$$

$$\Rightarrow \frac{eI}{F_p} = \frac{19.876 \times 500}{96500 \times 8.28}$$

$$\text{MRR} = 0.0124 \text{ cm}^3/\text{sec}$$

4.25.2 Electrode Discharge Machining

Gap between tool and work piece : 0.025 – 0.05

Centre line average value (R_a) : 0.25 μs

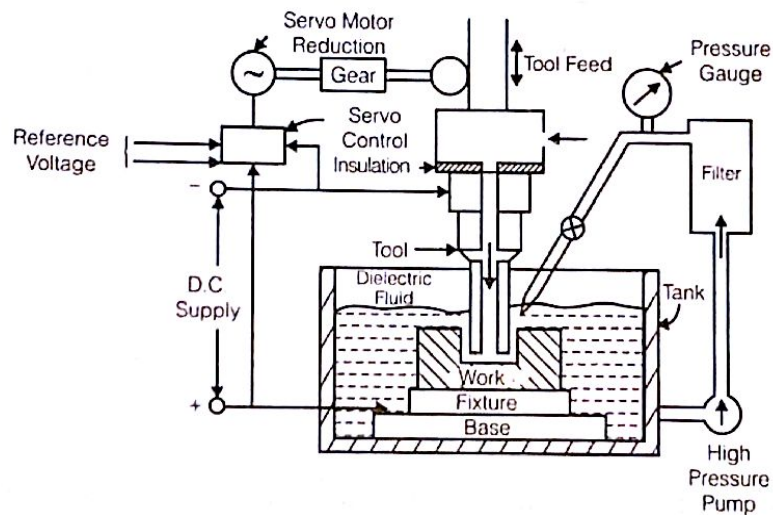


Fig. 4.39 (a) : Electrode discharge machining

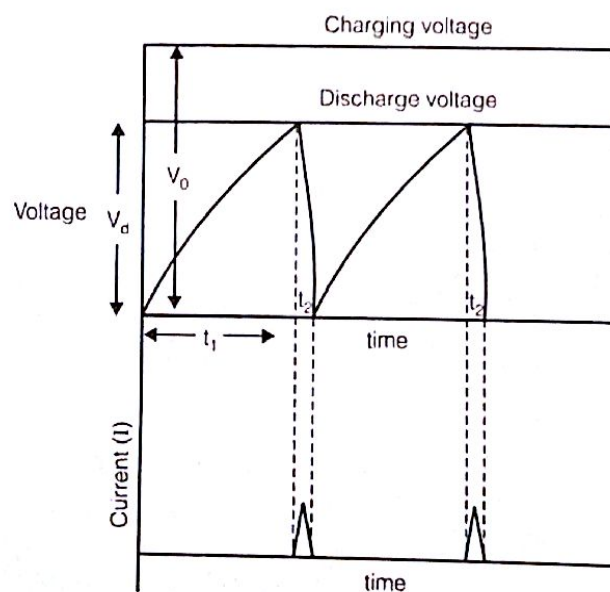


Fig. 4.39 (b) : Variation of current and voltage

EDM process is also called Spark Erosion machining where the material is removed by the erosion of repeated sparks. It is high voltage and low current process. During a major portion of cycle, a capacitor bank charges and once voltage reaches a threshold value, all the capacitors will discharge simultaneously, producing a spark at the tool tip. Dielectric becomes conducting only in that region. When spark hits the work piece, a crater will be produced over it. During the transportation of spark, a portion of kerosene also burns which provides solid lubrication in the machining process. During the machining process, a portion of tool material also melts out. So, materials like graphite are used to make the tools because they not only have higher melting point but also can be machined to a great degree of accuracy. To increase the conductivity copper is added in the graphite. When the thermal conductivity of work piece material increases, MRR decreases. The removed material starts accumulating in the tool work piece gap, so a servomechanism connected with the tool withdraws it and the flushing mechanism removes the material, servomechanism again places the tool back to its position. The different flushing systems are servomechanism, solenoid valve and stepper motor. Servomechanism maintains a mean spark gap voltage at a constant value.

The major application of the process is in Die Sinking and since the process produces cratering type surface. These surfaces are used in bearing applications.

If V_d is the discharge voltage, V_0 is charging voltage then

$$V_d = V_0 \left(1 - e^{-\frac{t}{RC}} \right) \quad \dots(1)$$

The frequency of spark $f = \frac{1}{t}$, so

$$f = \frac{1}{RC \log \left(\frac{V_0}{V_0 - V_d} \right)} \quad \dots(2)$$

It can be seen in Fig. 4.40 (b) that t_1 is the charging time and t_2 is discharge time. So energy released per spark

$$E = \frac{1}{2} CV_d^2$$

Average value of power delivered

$$P_{av} = \frac{E}{t_1 + t_2}$$

t_2 is very less as compared to t_1 so

$$P_{av} = \frac{1}{2} \frac{CR}{Rt_1} V_0^2 \left\{ 1 - e^{-\frac{t_1}{RC}} \right\}^2$$

$$\text{take } \frac{t_1}{RC} = N$$

$$P_{av} = \frac{1}{2} \frac{V_0^2}{RN} \left\{ 1 - e^{-N} \right\}^2$$

For maximum power delivery

$$\frac{dP_{av}}{dN} = 0$$

So after solving we get $N = 1.26$

So optimum value of discharge voltage

$$\frac{V_d}{V_0} = 1 - e^{-1.26}$$

$$= 0.72$$

V_d is 72% of charging voltage.

4.25.3 Ultrasonic Machining

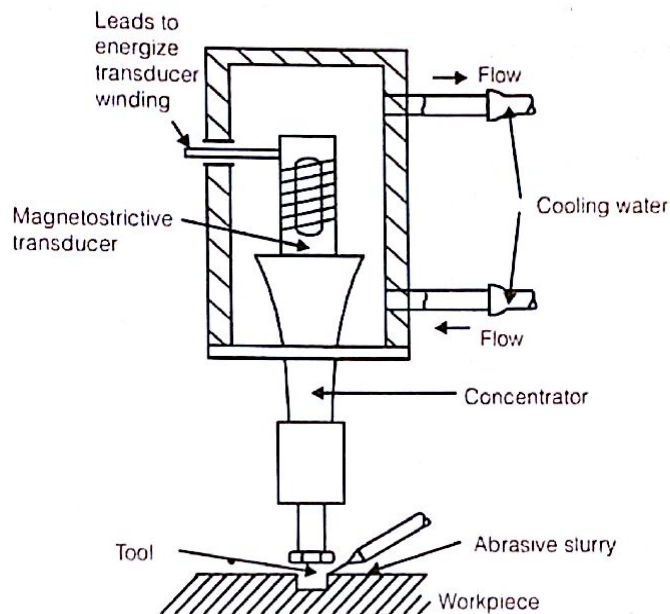


Fig. 4.40 (a) : Machining using ultra sonic machining

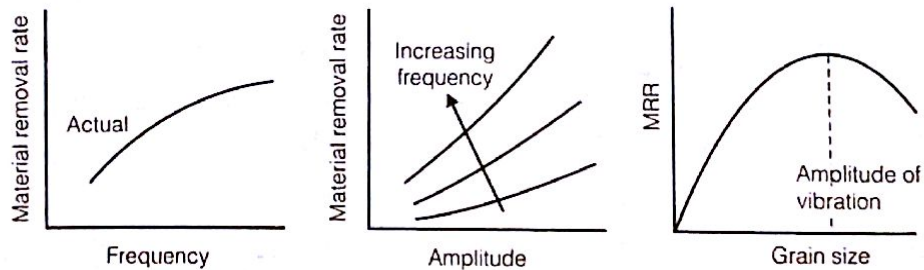


Fig. 4.40 (b) : Variation of MRR with respect to frequency and amplitude

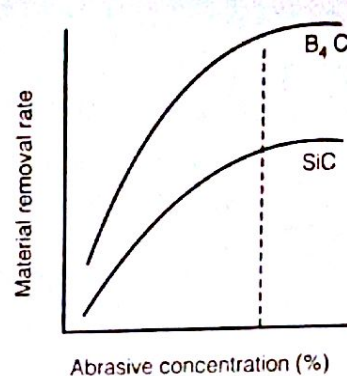
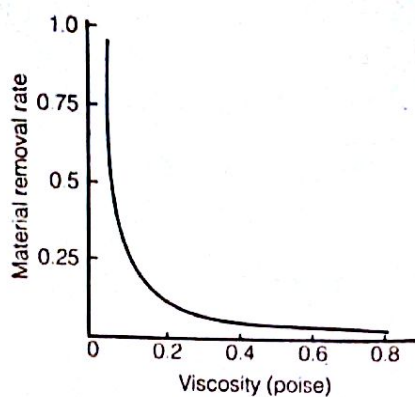


Fig. 4.40 (c) : MRR with respect to Viscosity Fig. 4.40 (d) : MRR with respect to % of abrasive

Ra : 0.25-0.75 μ s

Amplitude : 0.02-0.1 mm

Frequency : 15-30 kHz

Gap between tool and work piece : 0.25 mm

In Ultrasonic machining, tool is made up of ductile material. Between tool and workpiece, there is slurry of abrasives. Non-conducting brittle materials can be machined by this process like glasses and ceramics. Abrasive gets embedded into the tool and during the downward journey of the tool abrasives hammer the work piece, removing a material. This material will be flushed away from the machining area by the flow of slurry. Tool is made slightly tapered to produce straight holes. Upon increasing the viscosity of the carrier fluid, material removal rate decreases due to difficulty in flushing. By increasing the frequency, MRR will increase because number of impacts per unit time will increase. By increasing the amplitude, MRR will increase due to the increase of momentum of abrasives. By increasing the concentration of abrasives, impact will be there at more number of places which increases MRR. But when the concentration increases beyond a certain value, due to Collision between the abrasives momentum is lost, decreasing the MRR. By increasing the size of abrasive, an impact will appear on the larger area. But when the size increases beyond a certain value, momentum of abrasives will decrease. It should be noted that :

MRR : ECM > EDM > USM

Tool wear : USM > EDM > ECM

4.25.4 Abrasive Jet Machining

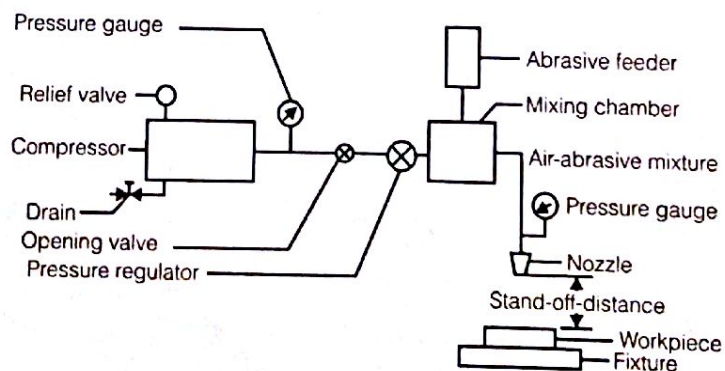


Fig. 4.41 (a) : Machining using abrasive machining

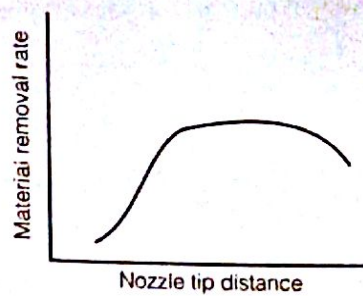


Fig. 4.41 (b) : Variation of MRR with respect to stand off distance

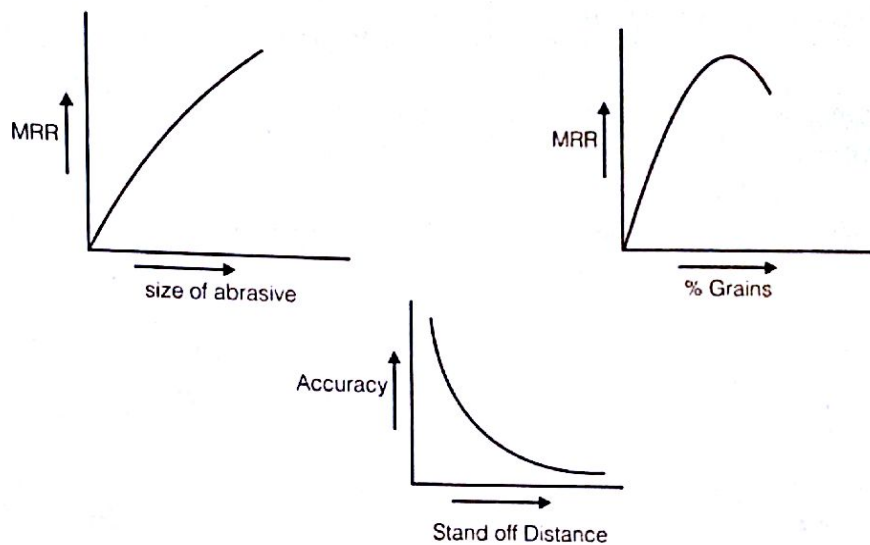


Fig. 4.41 (c) : Variation of MRR with respect to grain size, % of grains and stand off distance

For machining very fine holes of about 0.002 mm size, abrasive jet machining is used. Abrasives and air are mixed and thrown over the surface at a very high velocity. Due to the impact by the abrasive, a crack will be produced over the surface which will be blown by the air. The main applications of the process is, in machining inaccessible areas like inside surface of the bottle, cleaning metallic moulds, producing very fine holes in the tool for the purpose of lubrication, etc. By increasing the standoff distance, MRR will initially increase but due to mushrooming effect, when standoff distance increases beyond a certain value, both MRR and accuracy will decrease.

4.26 DRILLING

Drilling is an oblique cutting and it is a process of creating a hole. Drills are made by forging operation and the material used is HSS steel. The drills are made slightly smaller in size so that there is some margin for reaming. Drills are also tapered along its length so that it doesn't hit the finished part of the hole (due to any unbalanced forces).

Boring : Enlarging already existing hole to bring it to the required size and have a better finish. The accuracy expected is 0.125 mm.

Reaming : It is a process of exacting the hole and finishing it and has a fine surface finish of ± 0.005 mm.

Broaching : Process for super finishing.

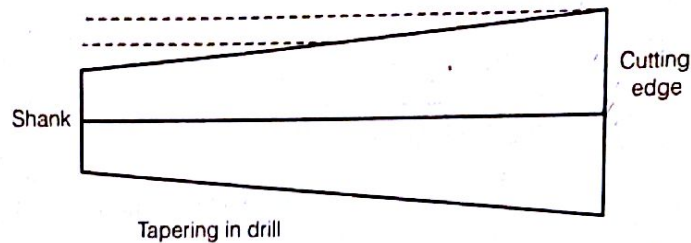


Fig. 4.42 : Showing tapering on a drill

Pack Drilling : Keeping a number of pieces together and drilling simultaneously.

Core Drilling : In casting operation holes are being created by using cores. This process is known as core drilling.

Trepanning : Drill is in the form of a tube at the periphery of which there are cutting edges. Complete material is not removed and initially this process was used in Gun Barrel manufacturing process. [Fig. 4.43 (a)].

Counter boring : Counter boring is making the hole little larger. Counter boring is done by end milling. It is seating place for bolt heads. The enlarged hole forms a square shoulder with the original hole. This is necessary in some cases to accommodate the heads of bolts, studs and pins. The cutting edges have straight or spiral teeth.

Counter sinking : It is the process of making the holes slightly tapered in the beginning. In counter sinking tools are used as shown in Fig. 4.43(c). It is a seating place for screws.

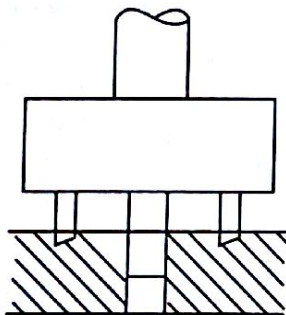


Fig. 4.43 (a) : Trepanning

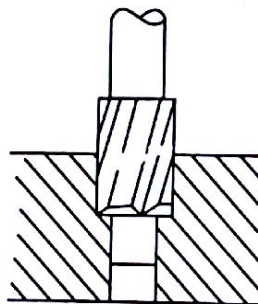


Fig. 4.43 (b) : Counter boring

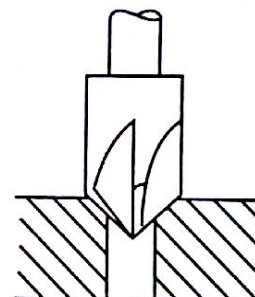
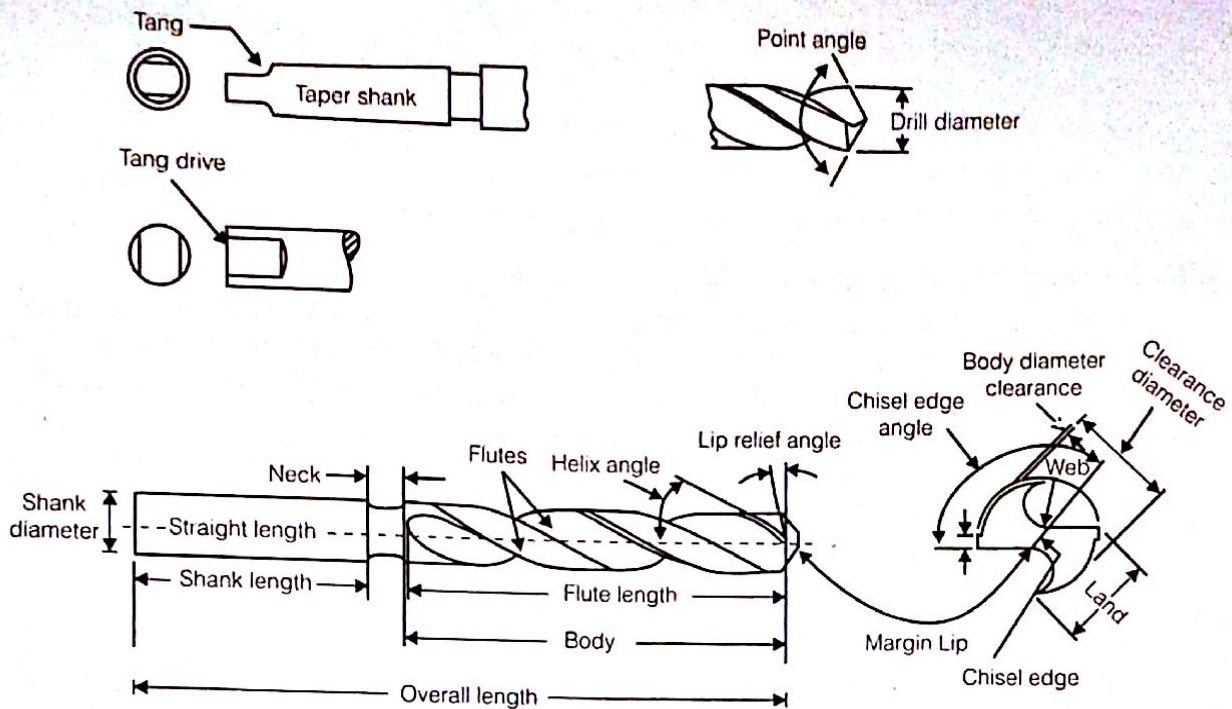


Fig. 4.43 (c) : Counter sinking

4.26.1 Drill Geometry

Following are major actions taking place at the point of a drill.

1. A small hole is pierced by the rotating web.
2. Chips are formed by rotating cutting edges.
3. Chips are conveyed out of the hole by helix.
4. The drill guided in the hole already produced.



$$\text{Lip angle} + \text{Lip relief angle} + \text{Helix angle} = 90^\circ$$

Fig. 4.44 : Drill geometry

Note on drill geometry :

1. A small web to reduce thrust on a drill but a large web for greater resistance to chipping and greater torsional rigidity.
2. Large flutes to provide a larger space for chip transfer but small flutes in the interest of torsional rigidity.
3. An increase in the helix angle to more quickly remove chips but a decrease in helix angle in the interest of greater strength of cutting edges.

The function of side cutting edge in single point cutting tool is the similar function of point angle in drilling. Following is the analysis of uncut chip thickness and width of chip in drill.

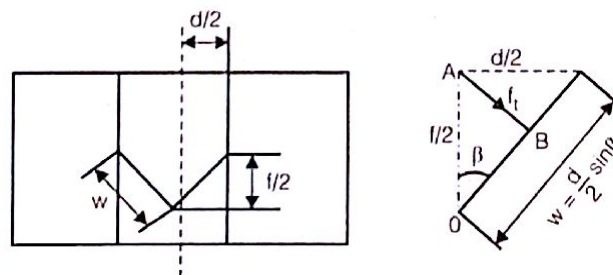


Fig. 4.45

$$w = \frac{d/2}{\sin \beta}$$

$$\Delta OAB : \frac{AB}{OA} = \sin \beta$$

$$AB = \frac{f}{2} \sin \beta = t_1$$

$$2\beta = \text{point angle,}$$

$$\text{feed} = \text{mm/rev}$$

How much angle the helix makes with the horizontal is called helix angle.

4.26.2 Important angles of a drill

Rake angle : It is the angle formed between a plane containing the drill axis and the leading edge of the land. It can have the positive, negative or zero value. For a right hand flute its value is positive, for a left hand flute its value is negative and for parallel flutes it is zero. Higher values are suitable for softer materials and lower values for harder materials. Larger the value of this angle lesser will be the power required in drilling. A line is drawn parallel to the drill axis passing through the cutting edge. The angle this line makes with a rake face is called back rake angle. At the centre, cutting edge merges into the chisel edge which is a flat area, so the back rake angle is zero. Towards the surface back rake angle increases and at the outer surface, since the cutting edge merges into the helix, back rake angle is equal to the helix angle.

Point angle : It is known as cutting angle. It is the angle included between the two opposite lips of a drill measured in a plane containing the axis of the drill and both lips. As it can be seen in the analysis (Fig. 4.44) that smaller is the point angle, chips will be thinner and wider. In case of ductile materials, if chips are thick, it will be jammed in the helix. So chips should be thinner.

Hence smaller point angles are used to drill ductile materials and larger point angles for drilling brittle materials.

Feed angle : Material on the back ground of cutting edge will form an angle which will try to hit the cutting edge and break it. This angle is called feed angle.

$$\tan \alpha = \frac{f}{2\pi r}$$

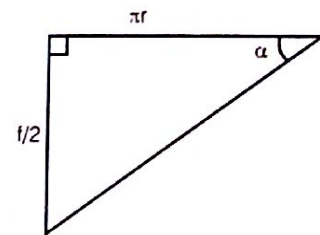


Fig. 4.46

Clearance angle : The angle formed between the flank and a plane normal to the drill axis, measured at the periphery of the drill. This angle is formed as a result of grinding the relief adjacent to the cutting edges to enable easy entry of the drill. Clearance angle is measure on the back side of the cutting edge, the angle which the background of cutting edge makes with the horizontal plane is called clearance angle. In single point tool clearance is provided to take care of elastic recovery. Since soft material exhibit more elastic recovery so larger clearance is provided. Ductile materials should be drilled at lower feeds and with larger clearance angles because such materials exhibit larger elastic recovery and clearance in drill has to compensate the feed angle and elastic recovery.

	Ductile	Brittle
Clearance angle	8-12°	6-9°
Point angle	118°	135°

Chisel edge angle : When the drill is viewed from its end, there appears to be an obtuse angle formed between the lip and the chisel edge, this is known as Chisel edge angle. The greater the angle the larger the clearance.

4.26.3 Machining time

$$T = \frac{L}{N \times f}$$

N = rpm of the drill

L = Length of axial travel of drill in mm

F = feed per rev in mm

T = machining time in min

$L = l + a$

l = depth or thickness of work piece

a = approach of drill = $0.3d$

d = diameter of drill

Cutting speed :

$$S = \frac{\pi d N}{1000} \text{ rpm}$$

$$= \frac{\text{Cutting speed in rpm}}{\pi \times d}$$

Example : 4.24

Through holes of 10 mm diameter are to be drilled in a steel plate of 20 mm thickness, drill spindle speed is 300 rpm feed is 0.2 mm/rev and drill point angle is 120° . Assuming drill over travel of 2 mm determine the time to produce a hole.

Solution :

$$N = 300 \text{ rpm}$$

$$f = 0.2 \text{ mm/rev}$$

$$\text{Point angle } 2\beta = 120^\circ$$

$$\text{over travel} = 2 \text{ mm}$$

$$\text{Total travel} = x + 20 + 2$$

$$\frac{d/2}{x} = \tan 60^\circ$$

$$x = \frac{10}{2 \tan 60^\circ}$$

$$x = 2.88 \text{ mm}$$

$$\text{Total travel} = 24.88 \text{ mm}$$

Number of revolutions required to make the hole

$$24.88 \text{ mm} = \frac{24.88}{0.2}$$

$$= 124.4 \text{ rev}$$

$$\text{Time} = \frac{124.4}{300}$$

$$= 0.414 \text{ min}$$

$$= 24.88 \text{ s}$$

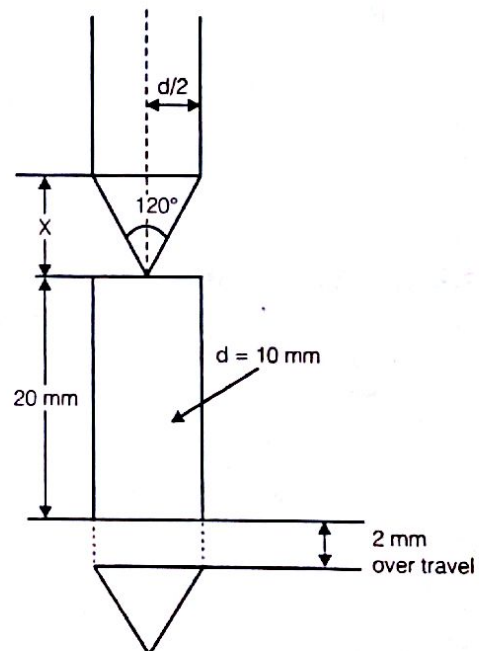


Fig. 4.47

4.27 MILLING

Milling is one of the machining processes of flat surfaces as well as formed surfaces like those of the gears, splines, slots and key ways etc.

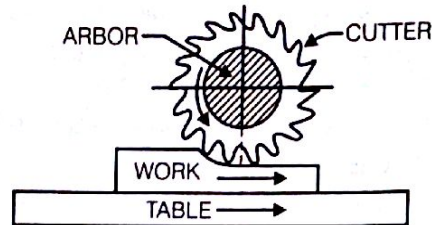


Fig. 4.48

There are two types of milling processes

- Peripheral milling (or slab milling)
- Face milling

4.27.1 Peripheral or slab milling operation

In the peripheral milling cutting teeth are on the periphery of the cutter. Movement of the tool or cutter is generatrix and movement of the work piece is directrix. In the slab milling operation, the axis of rotation of milling cutter is parallel to the work.

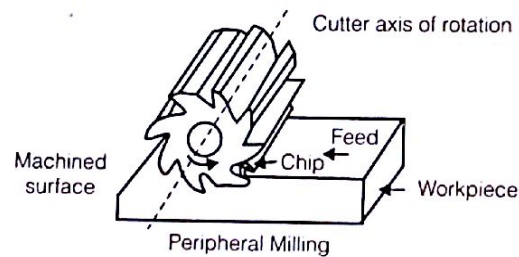


Fig. 4.49 : Schematic of peripheral milling

4.27.2 Face Milling

In the face milling operation, axis of rotation of cutter is perpendicular to the work. Because of the relative motion between the cutting teeth and work piece a face milling cutter leaves feeds marks on machine surface.

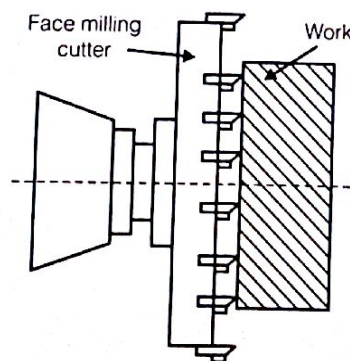


Fig. 4.50 : Schematic of face milling

4.27.3 End Milling

End milling cutter are combination of both slab milling and face milling operation. An end mill cutter is used to machine and produce a flat surface or a pair of parallel flat surfaces.

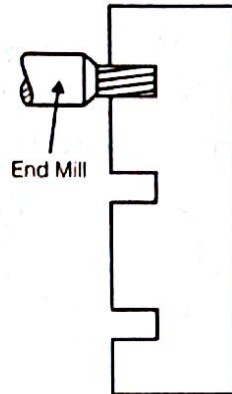


Fig. 4.51 : Schematic of end milling

4.27.4 Gang Milling

When a number of cutters are mounted on the arbor and a number of steps have been cut in the work piece, it is called Gang Milling.

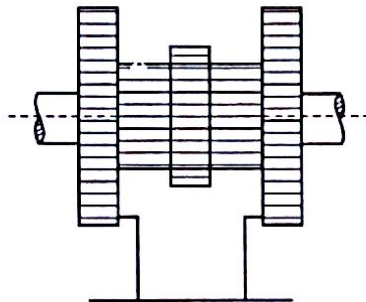


Fig. 4.52 : Schematic of Gang milling

4.27.5 Straddle Milling

When milling is performed on two surfaces simultaneously, it is called STRADDLE MILLING. T- Slot milling is a unique example of straddle milling by a single milling cutter.

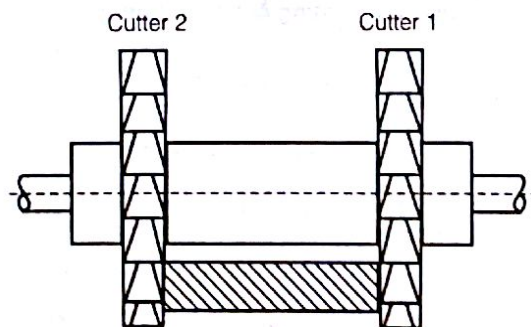


Fig. 4.53 : Schematic of Straddle milling.

4.27.6 Up Milling and Down Milling

In the up milling operation, cutter and the work piece movements are in opposite direction but in the down milling operation, both movements are in the same direction.

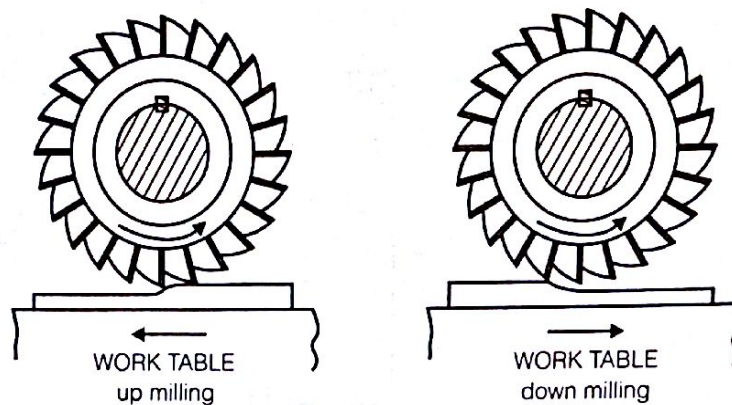


Fig. 4.54 : Up and Down Milling

In the up milling operation, chip thickness varies from minimum to maximum and before machining, cutting edge will rub over the finished part so the surface finish produced is very poor. In up milling operation, hot chips remains in the tooth space and be there for considerable period of time, so due to diffusion, tool life is lower in up milling. If back lash error is there in the fixture it has no significance in up milling because the fixtures are under tension opposite will be the case for down milling operation.

4.27.7 Mechanics of Milling

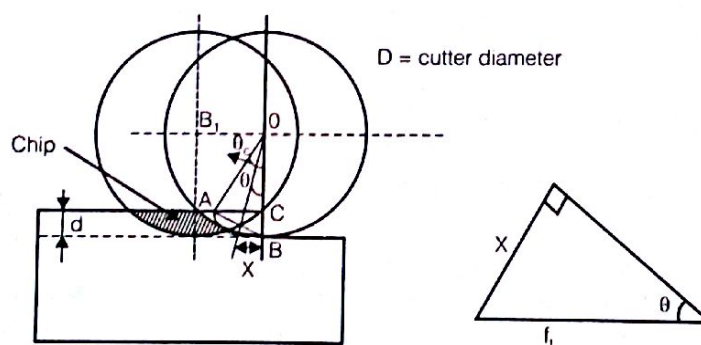


Fig. 4.55 : Cutting Action in Milling

$$f = \text{feed/rev}$$

$$f_t = \text{feed per tooth} = \frac{f}{n_t}$$

$$n_t = \text{no. of teeth}$$

$$x = f_t \sin \theta$$

$$\theta = \theta_C \quad x = x_{\max}$$

$$\theta = 0 \quad x = 0$$

$$x_{\max} = f_t \sin \theta_C$$

At

From $\triangle OAC$

$$\cos \theta_C = \frac{OC}{OA} = \frac{\frac{D}{2} - d}{\frac{D}{2}} \Rightarrow 1 - \frac{2d}{D}$$

$$\sin \theta_C = \sqrt{1 - \cos^2 \theta_C}$$

$$\Rightarrow \sin \theta_C = \sqrt{1 - \left(1 - \frac{2d}{D}\right)^2}$$

$$\Rightarrow \sin \theta_C = 2\sqrt{\frac{d}{D} \left(1 - \frac{d}{D}\right)}$$

4.27.8 Mean chip thickness

$$x_{\text{mean}} = \frac{0 + x_{\text{max}}}{2}$$

$$\frac{f_t \sin \theta_C}{2} = f_t \sqrt{\frac{d}{D} \left(1 - \frac{d}{D}\right)}$$

$$\text{Mean chip area } A_{\text{mean}} = w \times x_{\text{mean}}$$

Volume of metal removed

$$wdf = A_m V$$

V = Velocity of cutting

Uncut chip thickness is related to feed per tooth and by increasing the feed since there will be increase in the uncut chip thickness, cutting force requirement will increase. But while milling at the constant speed, cutting forces will be as it is but cutting power requirement will increase.

Example : 4.25

A surface $80 \times 160 \text{ mm}^2$ is rough machined using a face milling cutter of 150 mm diameter having 10 teeth. The cutter center is offset by 15 mm from the line of symmetry of work piece. Estimate the time to rough machine the surface if the feed per tooth 0.25 and cutting speed 20 m/min. With 5 mm approach and 5 mm over travel what is the single pass feed time? Also find the time to rough and finish machine the work if cutter is symmetric.

Solution :

For Rough Cut $A = 80 \times 160 \text{ mm}^2$

$D = 150 \text{ mm}$

$n_t = 10$

offset = 15 mm

$f_t = 0.25 \text{ mm/tooth}$

$V = 20 \text{ m/min}$

Movement = $160 + x$

From $\triangle OAB$ we get

$$x = 75 - \sqrt{75^2 - 55^2} = 24.0098$$

Total Movement of cutter = 184.0098 mm

Feed/rev = $0.25 \times 10 = 2.5 \text{ mm/rev}$

Number of revolution required for machining

$$= \frac{184}{2.5} = 73.6 \text{ rev}$$

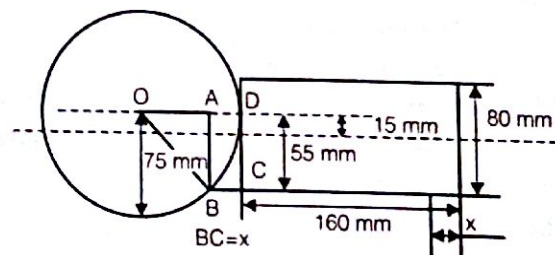


Fig. 4.56

$$V = \pi DN$$

$$20 = \pi \times 0.15 \times N$$

$$\text{rpm (N)} = 42.44 \text{ rev}$$

$$\text{machining time (T}_{\min}) = \frac{73.6}{42.44} = 1.7342 \text{ min}$$

For finish cut

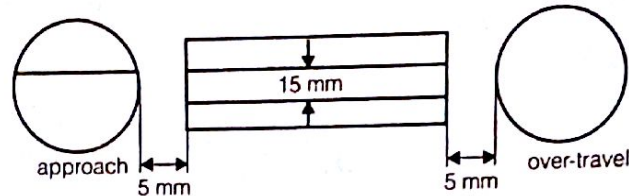


Fig. 4.57

$$\text{Total Movement of cutter} = 5 + 160 + 5 + 150 = 320 \text{ mm}$$

$$\text{Feed/rev} = 2.5 \text{ mm/rev}$$

$$\text{No. of revolutions} = \frac{320}{2.5} = 128 \text{ rev}$$

Time required to finish cut

$$T = \frac{128}{42.44} = 3.016 \text{ min}$$

If cutter axis is symmetrical

$$x = 75 - \sqrt{75^2 - 40^2} = 11.55$$

$$\text{Rough cut Movement} = 160 + x = 171.55 \text{ mm}$$

$$\text{No. of revolutions} = \frac{171.55}{2.5} = 68.62 \text{ rev}$$

$$T = \frac{68.62}{42.44} = 1.617 \text{ min}$$

There will not be any change in finish time.

Example : 4.26

The thickness of a rectangular brass plate of length L_w and width B_w has to be reduced by t mm in one pass by a helical fluted plain or slab milling cutter of length $l_c (> B_w)$, diameter D_c and number of teeth, Z_c at cutting velocity, V_c m/min and feed, S_0 mm/tooth. How will you determine the time that will be required to accomplish the aforesaid work? All other dimensions are in mm.

Solution :

$$l_c = \text{cutting length}$$

$$l_c > B_w$$

$$B_w = \text{width}$$

$$V_c = \text{m/min}$$

$$S_0 = \text{feed/tooth}$$

Length of cutter movement

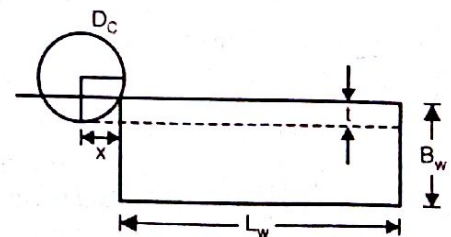


Fig. 4.58

$$x = \sqrt{\left(\frac{D_c}{2}\right)^2 - \left(\frac{D_c}{2} - t\right)^2}$$

$$\sqrt{D_c t - t^2} = \sqrt{t(D_c - t)}$$

Total length

$$L = L_w + x$$

$$\text{feed/rev} = Z_c S_0$$

$$V_c = \pi D_c N$$

$$N = \frac{V_c}{\pi D_c}$$

$$\text{No. of revolutions} = \frac{L_w + \sqrt{t(D_c - t)}}{Z_c S_0}$$

$$\text{Time of machining} = \frac{[L_w + \sqrt{t(D_c - t)}] \pi D_c}{Z_c S_0 V_c}$$

Example : 4.27

A 600 mm × 30 mm flat surface of a plate is to be finish machined on a shaper. The plate has been fixed with the 600 mm side along the tool travel direction. If the tool over-travel at each end of the plate is 20 mm, average cutting speed is 8 m/min, feed rate is 0.3 mm/stroke and the ratio of return time to cutting time of the tool is 1 : 2 what is the time required for machining.

Solution :

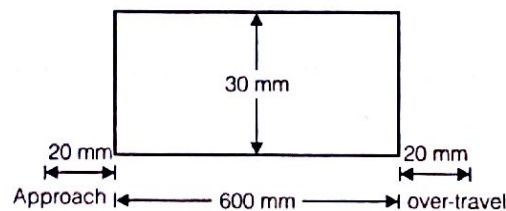


Fig. 4.59

$$\text{Total forward stroke length} = 20 + 600 + 20 = 640 \text{ mm}$$

$$\text{Forward time} = \frac{0.640}{8} \text{ min} = 0.08 \text{ min}$$

$$\text{Return time} = \frac{0.08}{2} = 0.04 \text{ min}$$

$$\text{Total time in completing one stroke} = 0.08 + 0.04 = 0.12 \text{ min}$$

$$\text{Number of strokes} = \frac{30}{0.3} = 100 \text{ strokes}$$

$$\text{Total machining time} = 0.12 \times 100 = 12 \text{ min}$$

Example : 4.28

Estimate the power required during up milling of mild steel block of 20 mm width with using a straight slab cutter with 10 teeth, 75 mm diameter and 10° radial rake. The feed velocity of table is 100 mm/min. The coefficient of friction at rake face and shear strength of material may be assumed to be 0.5 and 400 N/mm² respectively. The depth of cut is 5 mm and cutter rotates at 60 rpm.

Solution

$$D = 75 \text{ mm}, \alpha = 10^\circ, \mu = 0.5, \tau_s = 400 \text{ N/mm}^2$$

$$N = 60 \text{ rpm}, d = 5 \text{ mm}, Z = 10, w = 20 \text{ mm}$$

Feed per teeth per revolution

$$f = \frac{\text{Table feed}}{NZ} = \frac{F}{NZ}$$

$$= \frac{100}{60 \times 10} = \frac{1}{6} \text{ mm}$$

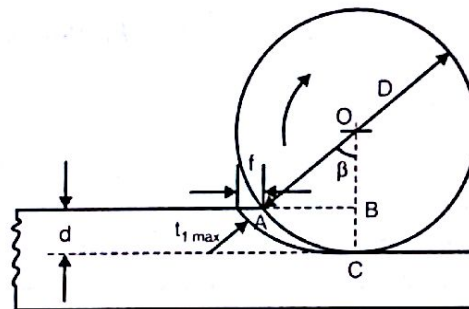


Fig. 4.60

Max. thickness of uncut chip

$$t_{1 \max} = f \sin \beta = \frac{1}{6} \sin (29.93) = 0.083156$$

$$\therefore (D - d).d = AB^2$$

$$AB = \sqrt{(D - d).d} = \sqrt{(75 - 5) \times 5} = 18.7 \text{ mm}$$

$$\sin \beta = \frac{AB}{AO} = \frac{18.7}{75/2} = \frac{18.7 \times 2}{75}$$

$$\beta = 29.93^\circ$$

$$\text{Angle between two teeth, } \theta = \frac{2\pi}{Z} = \frac{360}{10} = 36^\circ$$

$\therefore \theta > \beta$ so the cutting will be intermittent.

$$\text{Max. shear force, } F_{s \max} = \frac{\tau_s \cdot w \cdot t_{1 \max}}{\sin \phi} \quad \dots (1)$$

$$\text{Friction angle, } \lambda = \tan^{-1} \mu$$

$$= \tan^{-1} 0.5 = 26.565^\circ$$

From Lee-& shaffer condition of optimum power

$$\phi + \lambda - \alpha = 45$$

$$\phi + 26.565 + 10 = 45$$

$$\phi = 28.435^\circ$$

$$\therefore F_{s_{\max}} = \frac{400 \times 20 \times 0.083156}{\sin(28.435)} \\ = 1397.12 \text{ N}$$

$$\text{Max. cutting force, } F_c = \frac{F_s \cdot \cos(\lambda - \alpha)}{\cos(\phi + \lambda - \alpha)} \\ = \frac{1397.12 \times \cos(26.565 - 10)}{\cos 45} = 1893.825 \text{ N}$$

Max. torque on the cutter

$$M_{t_{\max}} = F_c \times D/2 \\ = 1893.825 \times \frac{75}{2 \times 1000} = 71.02 \text{ N-m.}$$

The torque variation is

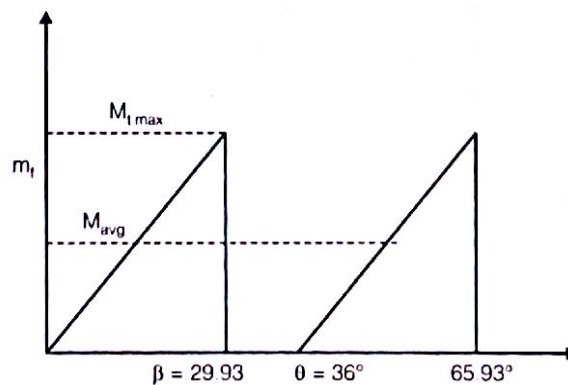


Fig. 4.61

Average torque

$$M_{\text{avg}} \times \theta = \frac{1}{2} \cdot M_{\text{max}} \cdot \beta$$

$$M_{\text{avg}} = \frac{M_{\text{max}} \times \beta}{2\theta} = \frac{71.02 \times 29.93}{72} \\ = 29.523 \text{ N-m}$$

$$\text{Power required} = M_{\text{avg}} \times \omega = 29.523 \times \frac{2\pi \times 60}{60} = 185.5 \text{ W}$$

Example : 4.29

In a slab milling operation with straight teeth cutter, the cutter has 15 teeth with 10° rake angle and rotates at 200 rpm. The diameter of cutter is 80 mm and table feed is 75 mm/min, the depth of cut is 5 mm. The width of ms slab is 50 mm and ultimate shear stress of work material is 420 N/mm^2 . Assuming the coefficient of friction between chip and cutter to be 0.7 and using Lee and shaffer relation, plot variation of resultant torque with cutter rotation and estimate avg. power consumption.

Solution :

$Z = 15, \alpha = 10^\circ, N = 200 \text{ rpm}, D = 80 \text{ mm}$

table feed, $F = 75 \text{ mm/min}, d = 5 \text{ mm}$

$\tau_s = 420 \text{ N/mm}^2, \mu = 0.7, w = 50 \text{ mm}$

Lee and shaffer relation

$$\phi + \lambda - \alpha = 45 \quad \dots (1)$$

$$\begin{aligned} \text{Friction angle, } \lambda &= \tan^{-1}(\mu) \\ &= \tan^{-1}(0.7) \\ &= 35^\circ \end{aligned}$$

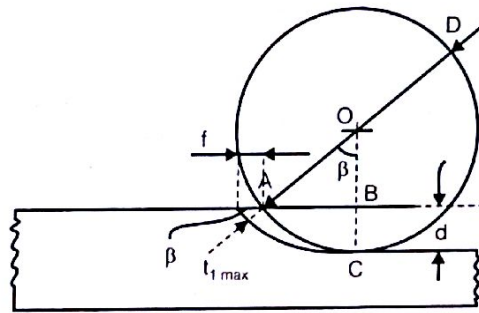


Fig. 4.62

$\therefore$ Shear angle from (1)

$$\phi + 35 - 10 = 45$$

$$\phi = 20^\circ$$

$\therefore$

$$(D - d) \cdot d = AB^2$$

$$AB = \sqrt{75 \times 5} = 19.365 \text{ mm}$$

$$\sin \beta = \frac{AB}{OA} = \frac{19.365}{40}$$

$$\beta = 28.96^\circ$$

Feed per teeth per revolution

$$f = \frac{F}{N \cdot Z} = \frac{75}{200 \times 15} = \frac{1}{40} \text{ mm}$$

Maximum thickness of uncut chip

$$t_{1 \max} = f \sin \beta$$

$$= \frac{1}{40} \sin(28.96) = 0.0121 \text{ mm}$$

Maximum shear force

$$F_{s \max} = \frac{\tau_s \cdot w \cdot t_{1 \max}}{\sin \phi}$$

$$= \frac{420 \times 50 \times 0.0121}{\sin 20} = 742.938 \text{ N}$$

Maximum cutting force,

$$F_{c \max} = \frac{F_s \cos(\lambda - \alpha)}{\cos(\phi + \lambda - \alpha)}$$

$$F_{c \max} = \frac{742.938 \times \cos(35 - 10)}{\cos 45} = 952.233 \text{ N}$$

Angle between torque teeth

$$\theta = \frac{360}{15} = 24^\circ$$

$\therefore \theta < \beta$ so there will be continuous cutting i.e. there will be one teeth in contact always. The variation is as

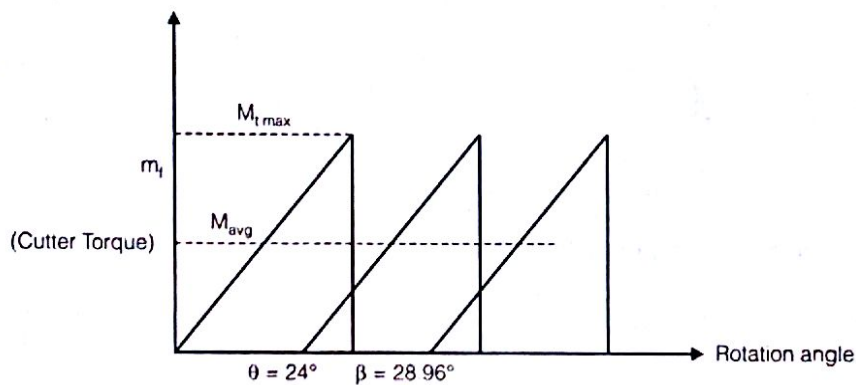


Fig. 4.63

torque due to one tooth

$$M_{t \max} = F_{c \max} D/2$$

$$= 952.33 \times \frac{40}{1000} = 38.0932 \text{ N-m}$$

Average Torque

$$M_{avg} \theta = \frac{1}{2} M_{\max} \beta$$

$$M_{avg} = \frac{1}{2} M_{\max} \frac{\beta}{\theta}$$

$$= \frac{38.0932}{2} \times \frac{28.96}{24} = 22.982 \text{ N-m}$$

(i) Power consumption

$$= M_{avg} \frac{2\pi N}{60}$$

$$= 22.982 \times 2\pi \times \frac{200}{60} = 481.426 \text{ W}$$

Example : 4.30

A slot 25 mm deep is to be cut through a workpiece 200 mm long with the help of HSS side and face cutter whose diameter is 150 mm and has 10 teeth. The cutting speed is 50 m/min and feed is 0.25 mm per teeth find

- (i) Table feed in mm/min.
- (ii) Total cutter travel.
- (iii) Time required to machine the slot.

Solution :

$$BC = 25 \text{ mm}, D = 150 \text{ mm}$$

$$l = 200 \text{ mm}, Z = 10$$

$$\text{Cutting speed, } V = 50 \text{ m/min}$$

$$\text{Cutter over travel - AB}$$

$$\begin{aligned} \therefore AB &= \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - d\right)^2} \\ &= \sqrt{\left(\frac{D^2}{4} - \frac{D^2}{4} - d^2 + D.d\right)} \\ &= \sqrt{(D.d - d^2)} \\ &= \sqrt{(150 \times 25 - 25^2)} = 55.9 \text{ mm} \end{aligned}$$

$$(i) \text{ Table feed} = \text{Feed per tooth} \times \text{no. of tooth} \times \text{rpm}$$

$$\therefore \text{Cutting speed, } V = \frac{\pi D N}{1000} \text{ m/min}$$

$$50 = \frac{\pi \times 150 \times N}{1000}$$

$$N = 106.1 \text{ rpm}$$

$$\therefore \text{Table feed} = 0.25 \times 10 \times 106.1 = 265.26 \text{ mm/min}$$

$$\begin{aligned} (ii) \text{ Total cutter travel} &= \text{length of W.P} + \text{Over travel} \\ &= l + AB \\ &= 200 + 55.9 \\ &= 255.9 \text{ mm} \end{aligned}$$

$$\begin{aligned} (iii) \text{ Slot machining time, } T &= \frac{\text{Total cutter travel}}{\text{Table feed}} = \frac{255.9}{265.26} \\ &= 0.9645 \text{ min} = 57.88 \text{ s} \end{aligned}$$

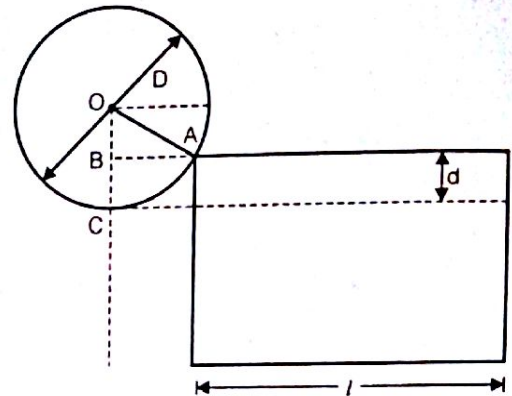


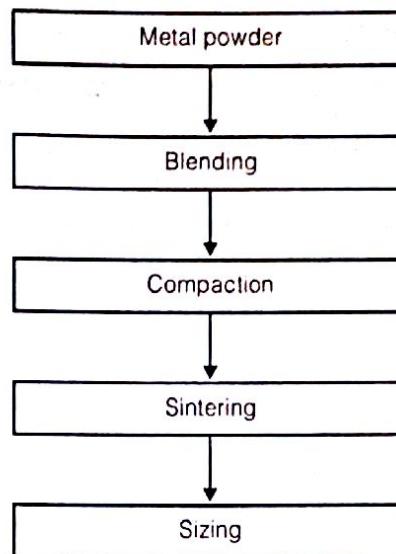
Fig. 4.64

4.28 POWDER METALLURGY

Powder metallurgy technique is used to mix the material which does not form an alloy. Some of the major applications of the process are:

1. Filament of a bulb, tube.
2. Cutting tool and grinding wheel.
3. Nozzles for abrasive jet machining.
4. Porous bearing or self lubricating bearing.
5. Filters used in casting process.
6. Friction material in anti-lock braking system (ABS).

Sequence of Processes in powder metallurgy



1. Methods of Making Metal Powders :

- **Metal Crushing and pulverizing** : Brittle materials can be converted into powder by crushing. If the material is not sufficiently brittle, its temperature is decreased.
 - **Atomization** : Ductile materials or the materials having low melting point, can be converted into powder by this method. Liquified material is poured over a high speed rotating disk. Due to the centrifugal action, liquid metal comes down in the form of very fine droplets. The material can also be sprayed by using a plasma torch.
 - **Corrosion** : When stainless steel is kept in the environment of sulphuric acid and copper sulphate, it dissolves and settles down at the bottom of tank. But this method takes time.
2. **Blending** : By mixing the lubricant with powders, a layer of lubricant will be deposited over the particles. This will increase the interaction between them and as a result of that powder can be given some shape called green compact. This is called as green because it is freshly prepared.
 3. **Compaction** : It is also called as Iso-static pressing. To give initial strength to the green compact, powder is pressed on a press. Variation in the properties of compact will be more when the compaction is done on a single or a double action press. But on a double action press, properties will be more uniform. Smaller is the size of particle, better will be under diffusion and the compact will be stronger. If the particle size is smaller, the strength will be better because more area will be under diffusion.

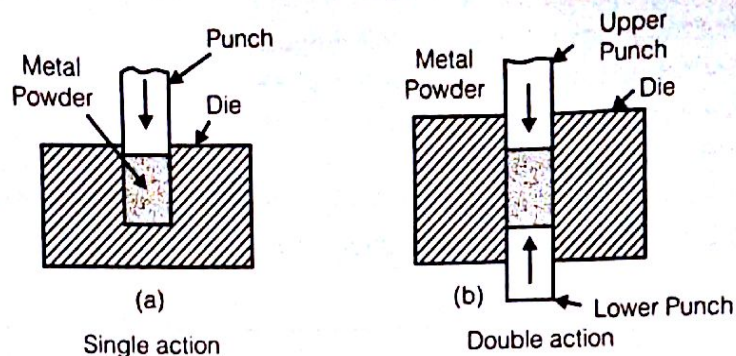


Fig. 4.65 : Compacting the metal powder using single and two punches

4. (a) **Pre-sintering** : When heating is done along with compaction it is called Hot Iso-static pressing (HIP). Compact is heated and due to that lubricant on the surface of particle will burn. Characteristic of lubricant should be such that after burning, it should not leave any residue. This provides the localized heating which increases the extent of diffusion between the particles. When Pre-sintering is clubbed compaction, it is called Hot Iso-static pressing. Rough particles give better strength as interlocking among the particles is better.
- (b) **Sintering** : In the sintering stage, compact is heated to 60-70% of the melting point of the base metal. This increases the extent of diffusion between the particles. Those powder which could not form interlocking and whose melting point are below this temperature, they will be liquified and will fill up the voids. When the compact is a mixture of large number of powders having large difference in their melting point two or three stage melting process is performed. After sintering, product appears to be very hard and brittle, so normally no machining is advisable but to give some simple shapes to the part sizing is performed. Powder metallurgy can only be applied for mass production because of expensive tooling arrangement.

4.29 JIGS AND FIXTURES

Jigs and fixtures are the auxiliary devices used in mass production. Fixture locate the work piece and Jig along with location, guides the tool. Jigs are used in drilling, boring, reaming etc. and fixtures are used in milling, shaping etc.

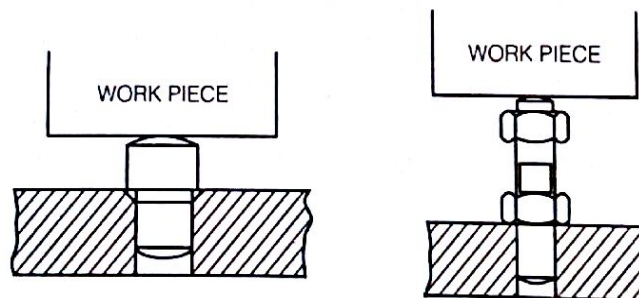


Fig. 4.66 : Fixed type support pin and adjustable type support pin

If deep holes are to be made in the work piece, the drill acts like a cantilever with point load (cutting forces). The hole becomes oversize in the beginning. Providing carbon bush makes it a simply supported beam and hence the drill does not get deflected.

Components of Jig and Fixture :

1. Locating elements
2. Clamping elements
3. Tool guiding
4. Main body

A work piece will have 12 degree of freedom

Translation

- + x - x
- + y - y
- + z - z

Rotation

- Clockwise and Anticlockwise - x
- Clockwise and Anticlockwise - y
- Clockwise and Anticlockwise - z

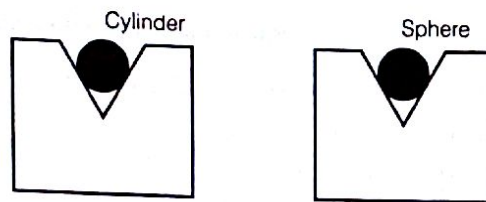


Fig. 4.67 : V block

The number of degree of freedom restricted when cylinder placed in a V block and are 7 when sphere is placed, only 3 degrees of freedom are restricted.

4.29.1 Principle of Location

3-2-1 Principle : There are 12 degree of freedom of a work piece i.e., movement about negative and positive axis and clock-wise and anti-clockwise rotation about the three axis. By providing three pins in the base, five degree of freedom will be arrested i.e. movement about negative Z-axis and the clockwise and anti clockwise rotation about X and Y axis. These three pins also ensure that machining always takes place on single plane perpendicular to the base, along the length direction. This arrests movement of work piece along negative Y-direction in clock-wise and anti -clock wise rotation about Z-axis. 2 pin are provided in a plane perpendicular to previous plane. This arrests 3 more degrees of freedom. A sixth pin is provided on a plane perpendicular to the previous two planes, which also arrests movement about negative X-axis. By providing six pins, nine degree of freedom is arrested. Two more Degree of freedom will be arrested by providing clamping elements and from 12th direction, tool comes for machining. A smaller size of pin is called button and are used in walls.

Radial location : This principle of location is used when there is already one drilled hole in the work piece. Since, there will be variation in the size of hole, conical pins are inserted in the hole to accommodate this variation. Two more pins are provided on the sides to arrest two more degree of freedom [Fig. 4.68(a)].

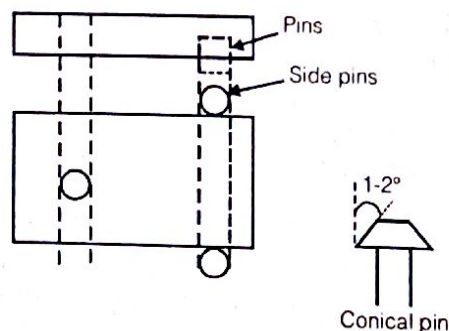


Fig. 4.68 (a) : Method of radial location

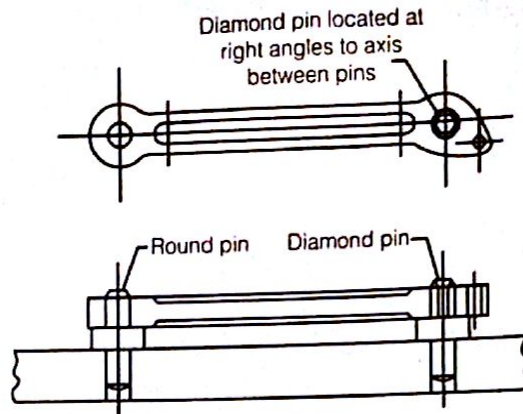


Fig. 4.68 (b) : Use of one round and one diamond locating pin

If there are two already drilled holes, in one hole a conical pin is provided and in the other hole, a diamond pin is provided to accommodate the variation in the centre distance Fig. 4.68(b). Two sides of the diamond pin are relieved and the diamond pins are always kept in the larger hole. Purpose of diamond pin is to arrest the variation in centre to centre distance between holes.

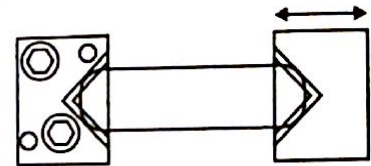


Fig. 4.69 : Method of V location

V-location : Radial locations are used when work piece is either cylindrical or spherical and when it is held between the 2-V jaws all the degrees of freedom will be arrested. One V is movable and the other one is fixed.

4.29.2 Steps in designing the jigs

- Draw the plan, elevation and end view with red pencil.
- Identify the areas where the machining has to be performed.
- Identify the type of location and where the locating element has to be given.
- Decide about the clamping element.

Outline diagram of Jig body:

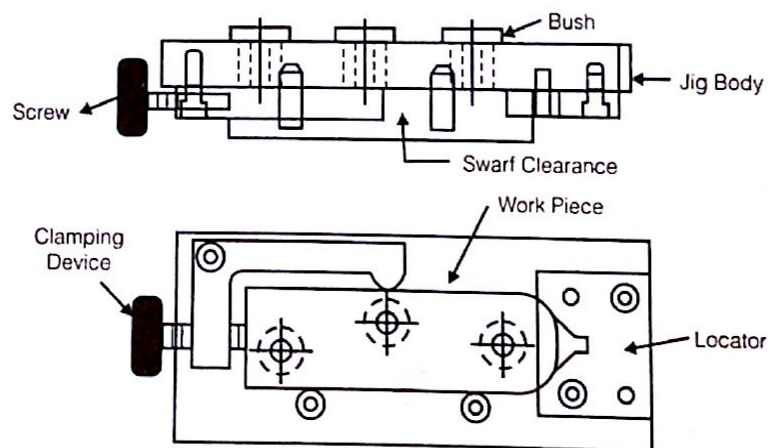


Fig. 4.70 : Showing the body of plate jig

Carbon bushes are either made of graphite or some soft material like aluminium so that it provides lubrication during machining. After some period of time, bushes will be consumed and have to be replaced. The clearance between the work piece and jig body is called swarf clearance and it is given to allow the free hand movement and to accommodate the chips.

4.30 SCREW THREAD MANUFACTURING

Methods of producing screw threads:

1. **Thread Chasing** : Producing screw threads over a lathe is called Thread Chasing and the hard automated lathe dedicated to produce screw threads is called Swiss Automat. A wire is fed through the spindle. It is turned, threads are being produced and by using a parting tool. The screw is cut off from the wire.

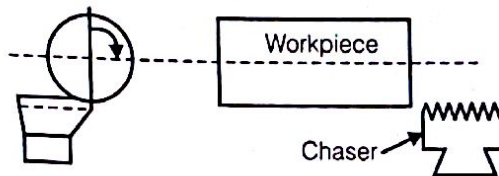


Fig. 4.71 : Thread chasing operation

2. **Die Threading** : External screw threads over pipes are cut by Die Threading. If the size of pipe increases beyond a certain value, the process cannot be used to create threads. If there is any change in the thread parameter, a different set of dies will be required.
3. **Tapping** : It is a process of creating internal threads manually. Different sizes of taps are available and a set consists of three sizes. If there is any change in the pitch or thread angle a separate sets of dies will be required similarly external threads can be cut by using dies. Relatively accurate threads are produced by dies.
4. **Thread milling** : Thread milling is employed when the screw threads finish very near to the shoulder of the work or the diameter is too large. In order to start the cutting action, the cutter axis is first swivelled and set at an angle equal to the helix angle of the screw. The work and cutter rotated in opposite directions. The work is also made to advance axially.
5. **Thread Rolling** : A work blank is pressed between either two flat dies or three circular die process and threads are produced by plastic deformation process. Because of work hardening threads are stronger and accurate but the process is used only for mass production and threads cannot be cut up to the shoulders. Threads produced by soft and ductile materials will be economical. If there is any change in the thread parameter a separate sets of dies will be required.

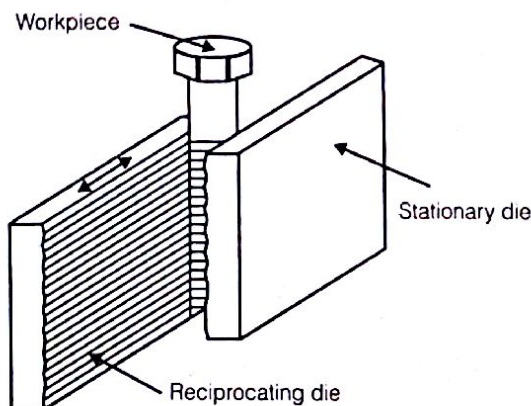


Fig. 4.72 (a) : Preparation of threads using flat rolling

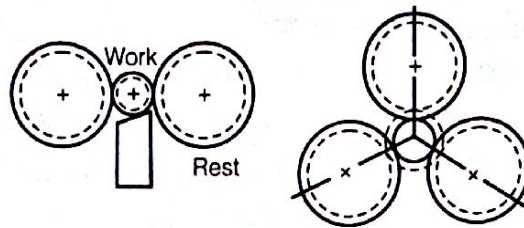


Fig. 4.72 (b) : Preparation of threads using circular rolling

6. **Thread grinding** : It is a type of form grinding with minimum in feed otherwise wheel wear will increase. This process primarily used to produce highly precise screw threads used in gauges.

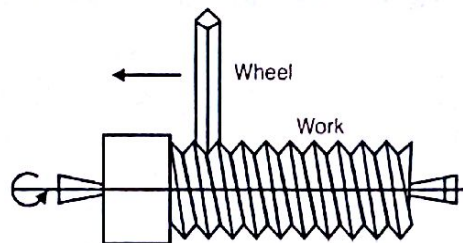


Fig. 4.73 : Preparation of threads using grinding

4.31 GEAR MANUFACTURING

4.31.1 Materials for Gears

1. **Cast Iron** : Large size gears are produced by casting process by this material. Care should be taken that on such gears, fatigue load should not appear.
2. **Steel** : Since the material has good load carrying capacity, such gears are used in power transmission.
3. **Bronze** : In worm gear drives, since heavy sliding loads appear, and bronze is very resistant to sliding loads, it is used to make Worm Gears.
4. **Plastics** : Used in noiseless operations like toys.
5. **Aluminium** : Aluminium is used where lightness of the assembly is the criteria but much power cannot be transmitted by these gears.
6. **Nylon** : Used in Xerox machines. These gears produce noiseless operation and can also carry small amount of loads.

4.31.2 Forming

1. **Rolling** : A number of work blanks are mounted on a common shaft and is pressed by a pair of rolls. Teeth's are produced by plastic deformation process so it will be strong. But a separate sets of rolls will be required if there is any change in any parameter of gear. For hard and brittle materials the process becomes very uneconomical.

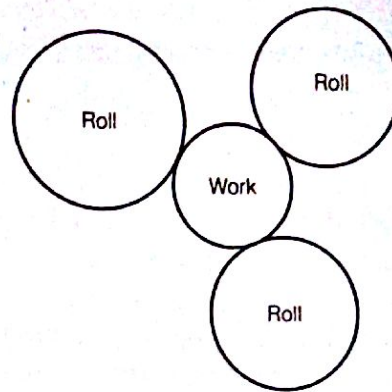


Fig. 4.74 : Preparation of gears using Rolling

2. **Extrusion** : Depending upon the shape of the die, teeth's will be produced over the gears. Both helical and spur gears can be produced by this process and the gear can be cut to the required size. Gears out of soft materials like plastic, nylon, aluminium can be manufactured easily.

4.31.3 Machining

Gear Milling : Gear cutting on milling can be performed either by using a slab milling cutter or end milling cutter. When the required tooth depth is achieved the cutter is withdrawn and the work piece is indexed and moved by '1' pitch, so, that a new position on the work blank comes in contact with its cutter. All types of gears including bevel can be produced by milling operation and since the indexing mechanism is governed by a gear arrangement, gears produced by milling operation are not very accurate.

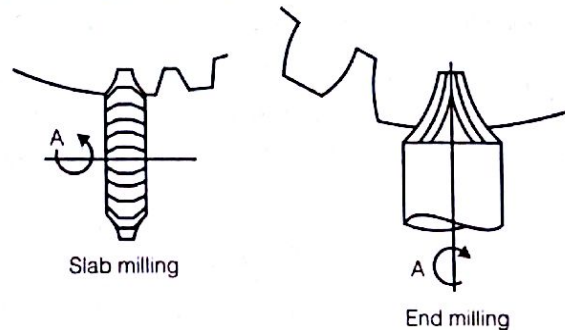


Fig. 4.75 : Preparation of gears using milling

Indexing Mechanism : The milling machine is having an index plate on which there are number of circles. On each circle there are finite number of holes. There is a pin over index plate which is in contact with a worm gear which has exactly 40 number of teeth. This worm gear is in mesh with worm wheel on which work blank is mounted. By giving one complete rotation to the index plate worm gear advances by '1' pitch. So, if 40 number of teeth's has to be produced over the work blank, after cutting one teeth the index plate should be given one rotation.

For example the index plate consists of 12, 14, 16, 18 no of holes. To find the no of revolutions ratio

$\frac{40}{N}$ is calculated. Suppose 28 teeth has to be cut on the work blank then:

$$\frac{40}{N} = \frac{40}{28} = 1 + \frac{12}{18} = 1 + \frac{3}{7} = 1 + \frac{6}{14}$$

After cutting each teeth, one complete revolution is given to the index plate and pin is inserted in the 8th hole of 14 hole circle.

If 70 teeth has to be cut:
$$\frac{40}{70} = \frac{4}{7} = \frac{4 \times 2}{7 \times 2} = \frac{8}{14}$$

The pin is provided in 8th hole in 14th hole circle after cutting each teeth.

Gear Shaping : In the rack type cutter, once all the cutting edges are covered by the work blank, rack is with drawn and the work is indexed. So, the gears produced are not very accurate. But with pinion type cutter, once the required tooth depth is achieved, rotary motions are given to both pinion and work and as a result of that, it is a continuous process. So, the gears produced are very accurate. Internal gears are also cut by this method. Both helical and spur gears can be cut by this procedure but to cut helical gears, work has to be mounted on a helical drive.

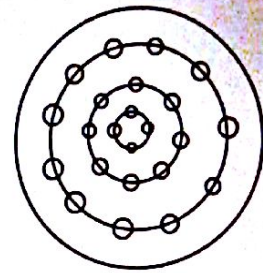


Fig. 4.76 : Indexing plate

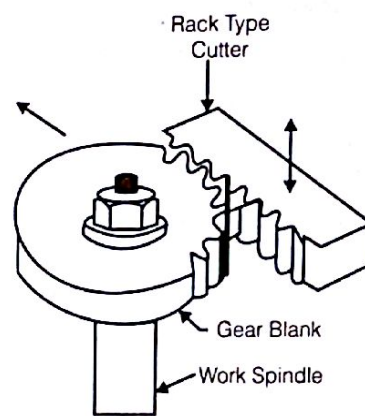


Fig. 4.77 : (a) Gears shaping using pinion cutting (b) Preparation of gears using shaper

Broaching : Splines broaches are used to produce gears. Initially, a pilot hole has to be drilled and a broach is pulled through it. All the teeth will be produced simultaneously. For producing external gears, pot broaching is used. Both helical and spur gears can be produced.

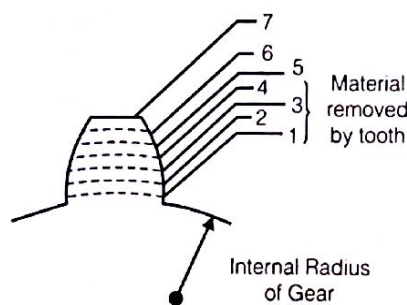


Fig. 4.78 : Preparation of gears using broaching

Gear Hobbing : Hob is in the shape of splined screw thread with a leading edge. A number of work blanks are mounted on a common shaft and the hob is lowered till the required tooth depth is achieved. After that three motions started simultaneously.

1. Rotation of work blank
2. Rotation of hob
3. Axial movement of work along the axis of hob.

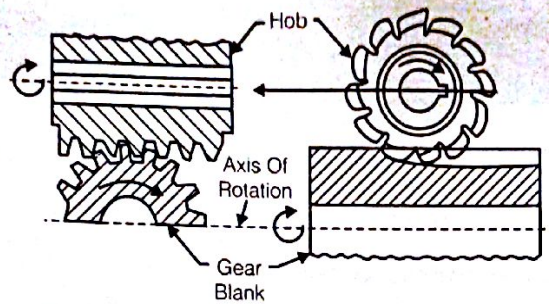


Fig. 4.79 (a) : Preparation of gears using hobbing

Initially the hob is in contact with the work with no rotation is given to the work. When the required tooth depth is achieved, all the three motions are started simultaneously. If it is a single start hob, in one rotation of the hob work piece should advance by '1' pitch. For double start hob, in half rotation of hob, the work should advance by '1' pitch.

Single start hob; $\frac{\text{Rpm of hob}}{\text{Rpm of work}} = N$

Double start hob; $\frac{\text{Rpm of hob}}{\text{Rpm of work}} = N/2$

Triple start hob; $= N/3$ and so on.

When the hob completes its movement along width of work blank all the teeth's are modelled.

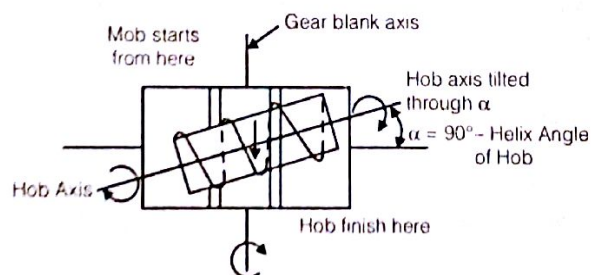


Fig. 4.80

Hobbing process is very versatile because by changing the angle between the work and hob helix angle of work can be changed. The process is not used to produce internal gears and gears up to shoulders. It is fastest process by which gears can be machined. To cut spur gears, the axis of hob is setoff from the normal to the rotational axis of the blank by the helix angle of the hob. In cutting helical gears the hob must be set over an additional amount equal to the helix angle of the gear. Once hob moves from one side to another, all the gears will be produced.

For spur gear; $\alpha = 90^\circ - \psi$

For helical gear; $\alpha = (90^\circ - \psi) + \text{helix angle of helical gear to be cut.}$

OOOO

PRACTICE QUESTIONS

1. The angle between the face and the flank of the single point cutting tool is known as:
 - (a) rake angle
 - (b) clearance angle
 - (c) lip angle
 - (d) point angle
2. Single point thread cutting tool should ideally have
 - (a) zero rake angle
 - (b) positive rake angle
 - (c) negative rake angle
 - (d) normal rake angle
3. Consider the following statements: Chipping of a cutting tool is due to
 1. Tool material being too brittle
 2. Hot hardness of the tool material is low
 3. High positive rake angle of the tool
 Which of these statements are correct?
 - (a) 1, 2 and 3
 - (b) 1 and 3
 - (c) 2 and 3
 - (d) 1 and 3
4. Consider the following statements about nose radius:
 1. It improves tool life
 2. It reduced the cutting force
 3. It improves the surface finish
 Which of these statements are correct?
 - (a) 1 & 2 are correct.
 - (b) 2 & 3 are correct
 - (c) 1 & 3 are correct.
 - (d) 1, 2 & 3 are correct
5. Consider the following characteristics
 1. The cutting edges is normal to the cutting velocity.
 2. The cutting forces occur in two directions only.
 3. The cutting edge is wider than the depth of cut
 The characteristics applicable to orthogonal cutting would include
 - (a) 1 and 2
 - (b) 1 and 3
 - (c) 2 and 3
 - (d) 1, 2 and 3
6. The primary tool force used to calculate the total power consumption in machining in the
 - (a) radial force
 - (b) tangential force
 - (c) axial force
 - (d) frictional force
7. Chip equivalent is increased by:
 - (a) an increase in side-cutting edge angle of tool
 - (b) an increase in nose radius and Side cutting edge angle of tool
 - (c) increase the area of cut
 - (d) increasing the depth of cut
8. In orthogonal turning of a low carbon steel bar of diameter 150mm with uncoated carbide tool, the cutting velocity is 90m/min. The feed is 0.24mm/rev and the depth of the cut is 2mm. The chip thickness obtained is 0.48 mm. If the orthogonal rake angle is zero and the principal cutting edge angle is 0° , the shear angle in degree is
 - (a) 20.56
 - (b) 26.56 ✓
 - (c) 30.56
 - (d) 36.56

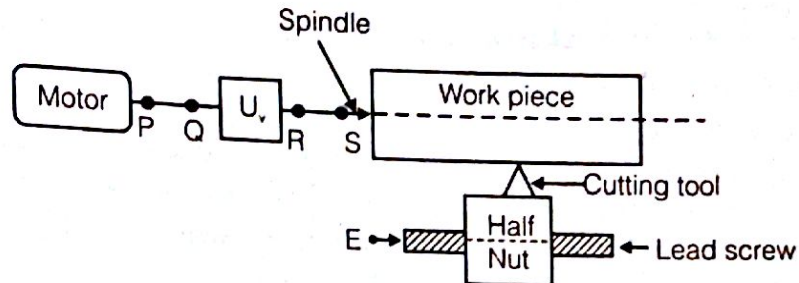
9. In orthogonal cutting, the feed is 0.5 mm at a cutting speed of 2m/s. If the chip thickness is 0.75 mm, the chip velocity is: (consider the rake angle as zero)
- (a) 1.33 m/s. (b) 2 m/s
(c) 2.5 m/s (d) 3 m/s
10. A batch of 10 cutting tools could produce 500 components while working at 50 rpm with a tool feed of 0.25mm/rev and depth of cut of 1mm. A similar batch of 10 tools of the same specification could produce 122 components while working at 80 rpm with a feed of 0.25mm/rev and 1mm depth of cut. How many components can produced with one cutting tool at 60 rpm?
- (a) 29 (b) 31
(c) 37 (d) 42
11. Consider the following elements:
1. Nose radius
 2. Cutting speed
 3. Depth of cut
 4. Feed
- The correct sequence of these elements in DECREASING order of their influence on tool life is:
- (a) 2, 4, 3, 1 (b) 4, 2, 3, 1
(c) 2, 4, 1, 3 (d) 4, 2, 1, 3
12. Consider the following statements with respect to relief angle of cutting tool.
1. This affects the direction of chip flow.
 2. This reduces excessive friction between the tool & work piece
 3. This affects tool life
 4. This allow better access of coolant the tool-workpiece.
- Which of the following statements given are correct?
- (a) 1 & 2 (b) 2 & 3
(c) 2 & 4 (d) 3 & 4
13. In a single point turning tool, the side rake angle and orthogonal rake angel are equal. ϕ is the principal cutting edge angle and its range is $0^\circ \leq \phi \leq 90^\circ$. The chip flows in the orthogonal plane. The value of ϕ is closest to
- (a) 0° (b) 45°
(c) 60° (d) 90°
14. In turning operation, the feed could be doubled to increase the metal removal rate. To keep the same level of surface finish, the nose radius of the tool should be:
- (a) halved (b) kept unchanged
(c) doubled (d) made 4 times
15. The radical force in single-point tool during turning operation varies between:
- (a) 0.2 to 0.4 times the main cutting force
(b) 0.4 to 0.6 times the main cutting force
(c) 0.6 to 0.8 times the main cutting force
(d) 0.5 to 0.6 times the main cutting force
16. **Assertion(A):** In metal cutting, the normal laws of sliding friction are not applicable.
Reason(R): Very high temperature is produced at the tool-chip interface.
- (a) Both A and R are individually true and R is the correct explanation of A.
(b) Both A and R are individually true but R is not the correct explanation of A.
(c) A is true but R is false
(d) A is false but R is true
17. In orthogonal turning of medium carbon stel, the specific machining energy is 2.0 J/mm³. the cutting velocity, feed and depth of cut are 120 m/min, 0.2 mm/rev and 2 mm respectively. The main cutting force in N is
- (a) 40 (b) 80
(c) 400 (d) 800

18. In an orthogonal cutting test, the cutting force and thrust force were observed to be 1000 N and 500 N respectively. If the rake angle of tool is zero, the coefficient of friction in chip-tool interface will be:
- (a) $\frac{1}{2}$ (b) 2
(c) $\frac{1}{\sqrt{2}}$ (d) $\sqrt{2}$
19. Power consumption in metal cutting is mainly due to:
- (a) tangential component of the force (b) longitudinal component of the force
(c) normal component of the force (d) friction at the metal-tool interface
20. Two tool P and Q have signature 8-5°-5°-6°-8°-30°-0° and 5°-5°-7°-7°-8°-15°-0° (both ASA) respectively. They are used to turn components under the same machining conditions. If h_P and h_Q denote the peak-to-valley heights of surfaces produced by the tool P and Q, the ratio h_P/h_Q will be
- (a) $\frac{\tan 8^\circ + \cot 15^\circ}{\tan 8^\circ + \cot 30^\circ}$ (b) $\frac{\tan 15^\circ + \cot 8^\circ}{\tan 30^\circ + \cot 8^\circ}$
(c) $\frac{\tan 15^\circ + \cot 7^\circ}{\tan 30^\circ + \cot 7^\circ}$ (d) $\frac{\tan 7^\circ + \cot 15^\circ}{\tan 7^\circ + \cot 30^\circ}$
21. Consider the following statements: The strength of a single point cutting tool depends upon:
1. Rake angle
 2. Clearance angle
 3. Lip angle
- Which of these statements are correct?
- (a) 1 and 3 (b) 2 and 3
(c) 1 and 2 (d) 1, 2 and 3
22. The angle of inclination of the rake face with respect to the tool base measured in a plane perpendicular to the base and parallel to the width of the tool is called:
- (a) back rake angle (b) side rake angle
(c) side cutting edge angle (d) end cutting edge angle
23. In orthogonal cutting test, the cutting force = 900 N, the thrust force = 600 N and chip shear angle is 30°. Then the chip shear force is
- (a) 1079.4 N (b) 969.9 N
(c) 479.4 N (d) 69.6 N
24. The time taken to face a work piece of 72 mm length, if the spindle speed is 80 rpm and cross-feed is 0.3 mm/rev, is
- (a) 1.5 minutes (b) 3.0 minutes
(c) 5.4 minutes (d) 8.5 minutes
25. In a machining operation chip thickness ratio is 0.3 and back rake angle of the tool is 10°. What is the value of shear strain?
- (a) 2.24 (b) 0.86
(c) 3.1 (d) 3.34
26. The percentage of total energy dissipated due to friction at the tool-chip interface is
- (a) 30% (b) 42%
(c) 58% (d) 70%

27. A medium carbon steel workpiece is turned on a lathe at 50 m/min cutting speed, 0.8 mm/rev feed and 1.5 mm depth of cut. What is the rate of metal removal?
 (a) 1000 mm³/min
 (b) 60000 mm³/min
 (c) 20000 mm³/min
 (d) can not be calculated with the given data.
28. In the selection of optimal cutting conditions, the requirement of surface finish would put a limit on which of the following?
 (a) the maximum feed
 (b) the maximum depth of cut
 (c) the maximum speed
 (d) the maximum number of passes
29. For increasing the material removal rate in turning, without any constraints, what is the right sequence to adjust the cutting parameters?
 1. Speed
 2. Feed
 3. Depth of cut
 Select the correct answer using the code given below:
 (a) 1-2-3
 (b) 2-3-1
 (c) 3-2-1
 (d) 1-3-2
30. During machining, excess metal is removed in the form of chip as in the case of turning on a lathe. Which of the following are correct? Continuous ribbon like chip is formed when turning
 1. at a higher cutting speed
 2. at a lower cutting speed
 3. a brittle material
 4. a ductile material
 Select the correct answer using the codes given below:
 (a) 1 and 3
 (b) 1 and 4
 (c) 2 and 3
 (d) 2 and 4
31. Consider the following statements
 In an orthogonal cutting the cutting ratio is found to be 0.75. The cutting speed is 60m/min and depth of cut 2.4 mm. Considering rake angle to be zero.
 1. chip velocity will be 45m/min
 2. chip velocity will be 80 m/min
 3. chip thickness will be 1.8mm
 4. chip thickness will be 3.2 mm
 Which of the following are correct?
 (a) 1 and 3
 (b) 1 and 4
 (c) 2 and 3
 (d) 2 and 4
- ✓ 32. A cylinder is turned on lathe with orthogonal machining principle. Spindle rotates at 200 rpm. The axial feed rate is 0.25 mm per revolution, depth of cut is 0.4 mm. The rake angle is 10°. In the analysis it is found that the shear angle is 27.75°. The thickness of the produced chip is
 (a) 0.511 ,
 (b) 0.528
 (c) 0.818 ,
 (d) 0.846
- ✓ 33. In the above problem, the coefficient of friction at the chip total interface obtained using Earnest and merchant theory is
 (a) 0.18
 (b) 0.36
 (c) 0.71
 (d) 0.98
34. Consider the following statements
Assertion (A): In a Swiss -type automatic lathe, the turret is given longitudinal feed for each tool in a specific order with suitable indexing.
Reason (R): A turret is a multiple tool holder to facilitate machining with each tool by indexing without the need to change the tools.
 (a) Both A and R are individually true and R is the correct explanation of A.
 (b) Both A and R are individually true. but R is not the correct explanation of A.

- (c) A is true but R is false.
(d) A is false but R is true.
35. The cutting tool material normally used for turning steel of very high hardness is
(a) HSS (b) Tungsten carbide
(c) CBN (d) Diamond
36. A 400 mm long shaft has a 100 mm tapered step at the middle with 4° included angle. The tailstock offset required to produce this taper on a lathe would be:
(a) $400 \sin 4^\circ$ (b) $400 \sin 2^\circ$
(c) $100 \sin 4^\circ$ (d) $100 \sin 2^\circ$
37. Apart from hexagonal turret, the element(s) in a turret lathe include(s)
(a) cross-slide tool post (b) cross-slide tool post and rear tool post
(c) cross-slide tool post and tail stock (d) rear tool post and tail stock
38. Which one of the following sets of forces are encountered by a lathe parting tool while groove cutting?
(a) Tangential, radial and axial (b) Tangential and radial
(c) Tangential and axial (d) Radial and axial
39. The spindle speed range in a general-purpose lathe is divided into steps which approximately follow:
(a) Arithmetic progression (b) Geometric progression
(c) Harmonic progression (d) Logarithmic progression
40. Consider the following statements associated with the lathe accessories:
1. Steady rest is used for supporting a long job in between head stock and tail stock.
2. Mandrel is used for turning small cylindrical Job.
3. Collets are used for turning Disc-shaped job of these statements.
(a) 1 and 2 are correct (b) 2 and 3 are correct
(c) 3 alone is correct (d) 1 alone is correct
41. The indexing of the turret in a single-spindle lathe is done using:
(a) Geneva mechanism (b) Ratchet and pawl mechanism
(c) Rack and pinion mechanism (d) Whit worth mechanism
42. The percentage of carbon in gray cast iron is in the range of
(a) 0.25 to 0.75 percent (b) 1.25 to 1.75 percent
(c) 3 to 4 percent (d) 8 to 10 percent
43. In a machine tool gear box, the smallest and largest spindles are 100rpm and 1120 rpm respectively. If there are 8 speeds in all, the forth speed will be:
(a) 400 rpm (b) 280 rpm
(c) 800 rpm (d) 535 rpm
44. Machine tool manufacturers prefer grey cast-iron grade 40 for producing machine columns and tables because grey cast-iron is:
1. Heavy
2. Easily castable
3. Easily weldable
4. Having good damping capacity
Select the correct answer using the code below:
(a) 1 and 2 (b) 2 and 4
(c) 1 and 3 (d) 3 and 4

45. The figure shows an incomplete schematic of a conventional lathe to be used for cutting threads with different pitches. The speed gear box U_v is shown and the feed gear box U_s is to be placed. P, Q, R and S denotes locations and have no other significance. Changes in U_v should NOT affect the pitch of the thread being cut and changes in U_s should not affect the cutting speed.



- The correct connections and the correct placement of U_s are given by
- Q and E are connected, U_v is placed between P and Q
 - S and E are connected, U_v is placed between R and S
 - Q and E are connected, U_v is placed between S and E
 - S and E are connected, U_v is placed between S and E
46. For taper turning on centre lathes, the method of swiveling the compound rest is preferred for:
- Long jobs with small taper angles
 - Long jobs with steep taper angles
 - Short jobs with small taper angles
 - Short jobs with steep taper angles
47. It is required to cut screws threads with double start and 2 mm pitch on a lathe having lead screw pitch of 6 mm. What is the speed ratio between lathe and screw?
- 1 : 3
 - 3 : 1
 - 2 : 3
 - 3 : 2
48. **Assertion (A):** in a multi-spindle automatic lathe, the turret tool holder is indexed to engage the cutting tools by one by one for successive machining operations
Reason (R): Turret is a multiple tool holder so that for successive machining operation, the tools need not be changed.
- Both A and R are individually true and R is the correct explanation of A.
 - Both A and R are individually true and R is not the correct explanation of A.
 - A is true but R is false.
 - A is false R is true.
49. **Assertion (A):** A chip breaker is employed to improve the machinability of brass
Reason (R): A chip breaker facilitates the curling and breakage of long continuous chips.
- Both A and R are individually true and R is the correct explanation of A.
 - Both A and R are individually true but R is not the correct explanation of A.
 - A is true but R is false.
 - A is false but R is true.
50. Consider the following work materials:
- | | |
|--------------------|-------------------|
| 1. titanium | 2. mild steel |
| 3. stainless steel | 4. Grey cast iron |
- The correct sequence of these materials in terms of increasing order of difficulty in machining is:
- 4, 2, 3, 1
 - 4, 2, 1, 3
 - 2, 4, 3, 1
 - 2, 4, 1, 3

51. Consider the following statement: During third stage of tool-wear, rapid deterioration of tool edge takes place because
1. Flank wear is only marginal.
 2. Flank wear is large.
 3. Temperature of tool increase gradually.
 4. Temperature of tool increase drastically.
- (a) 1 and 3 (b) 2 and 4
(c) 1 and 4 (d) 2 and 3
52. The type of wear that occurs due to cutting action of the particles in the cutting fluid is referred to as
- (a) adhesion wear (b) diffusion wear
(c) erosive wear (d) corrosive wear
53. Flank wear occurs mainly on which of the following
- (a) Nose part and top face
(b) Cutting edge only
(c) Nose part, front relief face, and side relief face of cutting tool
(d) Face of carrying tool at a short distance from the cutting edge
54. **Assertion (A):** Non-ferrous materials are best machined with diamond tools.
Reason (R): Diamond tools are suitable for high speed machining.
- (a) Both A and R are individually true and R is the correct explanation of A.
(b) Both A and R are individually true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.
55. **Assertion (A):** The characteristics feature of high speed steel is its red hardness.
Reason (R): Chromium and cobalt in High Speed Steel promote martensite formation when the tools is cold worked
- (a) Both A and R are individually true and R is the correct explanation of A.
(b) Both A and R are individually true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.
56. The straight grades of cemented carbide cutting tool materials contain:
- (a) tungsten carbide only (b) tungsten carbide and titanium carbide
(c) tungsten carbide and cobalt (d) tungsten carbide and coal carbide
57. **Assertion (A):** During cutting, the diamond is kept flooded with coolant.
Reason (R): The oxidation of diamond starts at about 450°C
- (a) Both A and R are individually true and R is the correct explanation of A.
(b) Both A and R are individually true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.
58. Crater Wear is predominant in:
- (a) carbon steel tools (b) tungsten carbide tools
(c) high speed steel tools (d) ceramic tools

59. A machinist desires to turn a round steel stock of outside diameter 100 mm at 1000 rpm. The material has tensile strength of 75 kg/mm². The depth of the cut chosen is 3mm at a feed rate of 0.3 mm/rev. Which one of the following tool materials will be suitable for machining the component under the specified cutting conditions?

(a) Sintered carbides
(b) Ceramic
(c) HSS
(d) diamond

60. **Assertion (A):** Cutting tools made of high carbon steel have shorter tool life.

Reason (R): During machining, the top of the cutting tool is heated to 600/700°C which causes the tool tip to lose its hardness.

(a) Both A and R are individually true and R is the correct explanation of A.
(b) Both A and R are individually true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

61. Consider the following statements:

Assertion (A): Ceramic tools, are used for light, smooth and continuous cuts at high speeds.

Reason (R): Ceramics have high wear resistance and high temperature resistance.

(a) Both A and R are individually true and R is the correct explanation of A.
(b) Both A and R are individually true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

62. Match **List-I** (ISO classification of carbide tools) with **List-II** (Applications) and select the correct answer using the codes given below the lists:

List-I

A. P-10
B. P-50
C. K-10
D. K-50

Codes:

List-II

1. Non-ferrous, roughing cut
2. Non-ferrous, finishing cut
3. Ferrous material, roughing cut
4. Ferrous material, finishing cut

	A	B	C	D
(a)	4	3	2	1
(b)	3	4	2	1
(c)	2	4	3	1
(d)	3	4	1	2

63. **Assertion (A):** Cemented carbide Tool tips produced by powder metallurgy.

Reason (R): Carbides cannot be melted and cast.

(a) Both A and R are individually true and R is the correct explanation of A.
(b) Both A and R are individually true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

64. Consider the following statements: for precision machining of non-ferrous alloys, diamond is preferred because it has:

1. low coefficient of thermal expansion
2. high wear resistance
3. high compression strength
4. low fracture toughness

Which of these statements are correct

- (a) 1 and 2
(b) 1 and 4
(c) 2 and 3
(d) 3 and 4

65. Consider the following tool materials:

1. HSS
2. Ceramics
3. Cemented carbide
4. Diamond

The correct sequenced of these materials in the descending order of their cutting speeds is:

- (a) 4, 3, 1, 2
(b) 4, 3, 2, 1
(c) 3, 4, 2, 1
(d) 3, 4, 1, 2

66. Consider the following statements:

Assertion (A): Negative rake is usually provided on carbide tipped tools.

Reason (R): Carbide tools are weaker in compression.

- (a) Both A and R are individually true and R is the correct explanation of A.
(b) Both A and R are individually true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

67. Which one of the following is the hardest cutting tool material next only to Diamond?

- (a) cemented carbides
(b) ceramics
(c) silicon
(d) cubic boron nitride

68. The correct sequence of cutting tools in ascending order of their wear resistance is:

- (a) HSS-Cast nonferrous alloy (Stellite)-Carbide-Nitride
(b) Cast non-ferrous alloy (Stellite)-HSS-Carbide-Nitride
(c) HSS-Cast non-ferrous alloy (Stellite)-Nitride-Carbide
(d) Cast nonferrous alloy (Stellite)-Carbide-Nitride-HSS

69. Consider the following statements:

An increase in the cobalt content in the straight carbide grades of carbide tools:

1. Increases the hardness
2. Decreases the hardness
3. Increases the transverse rupture strength
4. Lowers the transverse rupture strength

Which of the statements given above are correct?

- (a) 1 and 3
(b) 2 and 4
(c) 1 and 4
(d) 2 and 3

70. Consider the following statements:

Assertion (A): carbide tips are generally given negative rake angle.

Reason (R): carbide tips are made from very hard materials.

- (a) Both A and R are individually true and R is the correct explanation of A.
(b) Both A and R are individually true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

71. Which of the following indicate better machinability?

1. smaller shear angle
2. higher cutting forces
3. longer tool life
4. better surface finish
(a) 1 and 3
(b) 2 and 4
(c) 1 and 2
(d) 3 and 4

72. Assertion (A): the machinability of a material can be measured as an absolute quantity.

Reason (R): machinability index indicates the ease with which a material can be machined.

- (a) Both A and R are individually true and R is the correct explanation of A.
- (b) Both A and R are individually true but R is not the correct explanation of A.
- (c) A is true but R is false.
- (d) A is false but R is true.

73. Poor machinability of centrifugally cast iron pipe is due to:

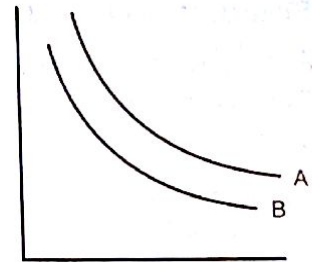
- (a) Chilling
- (b) Segregation
- (c) Dense structure
- (d) High mould rotation speed

74. The tool life curves for two tools A and B are shown in the figure and they follow the tool life equation $VT^n = C$. Consider the following original statements:

- 1. Value of n for both the tools is same
- 2. value of C for both the tools is same
- 3. value of C for tool A will be greater than that for the tool B.
- 4. value of C for tool B will be greater than that for the tool

A. which of these statements are correct

- (a) 1 and 3
- (b) 1 and 4
- (c) 2 only
- (d) 4 only



75. What is the variation of cutting speed with tool life on Log-Log scale?

- (a) Parabolic variation
- (b) Straight line variation
- (c) Hyperbolic variation
- (d) Elliptical variation

76. Consider the following criteria in evaluating machinability:

- 1. Surface finish
- 2. Type of chips
- 3. Tool life
- 4. Power consumption

In modern high speed CNC machining with coated carbide tools. The correct sequence of these characteristics in DECREASING order of their importance is:

- (a) 1, 2, 4, 3
- (b) 2, 1, 4, 3
- (c) 1, 2, 3, 4
- (d) 2, 1, 3, 4

77. In a machining operation, doubling the cutting speed reduces the tool life to $1/8$ th of the original value. The exponent n in Taylor's tool life equation $VT^n = C$, is

- (a) $\frac{1}{8}$
- (b) $\frac{1}{4}$
- (c) $\frac{1}{3}$
- (d) $\frac{1}{2}$

78. In a single-point turning operation to steel with a cemented carbide tool, Taylor's tool life exponent is 0.25. If the cutting speed is halved, the tool life will increase by

- (a) Two times
- (b) Four times
- (c) Eight times
- (d) Sixteen times

79. In a tool life test, doubling the cutting speed reduces the tool life to one fourth of the original. the Taylor's tool life index is:

- (a) $\frac{1}{2}$ (b) $\frac{1}{3}$
(c) $\frac{1}{4}$ (d) $\frac{1}{4}$

80. Which of the following values of index n is associated with carbide tools when Taylor's tool life equation $V.T^n = \text{constant}$ is applied?

- (a) 0.1 to 0.15 (b) 0.2 to 0.4
(c) 0.45 to 0.6 (d) 0.65 to 0.9

Statement for Linked Answer Question (81 and 82) :

A low carbon steel bar of 147 mm diameter with uncoated carbide insert. The observed tool lives are 24 min and 12 min for cutting velocities of 90 m/min and 120 m/min respectively. The feed and depth of cut are 0.2 mm/rev and 2 mm respectively. Use the unmachined diameter to calculate the cutting velocity.

81. What tool life is 20 min, the cutting velocity in m/min is

- (a) 87 (b) 97
(c) 107 (d) 114

82. Neglect over-travel are approach of the tool. when tool life is 20 min, the machining time in min for a single pass is

- (a) 5 (b) 10
(c) 15 (d) 20

83. Which of the following are machinability criteria?

1. Tool life
2. Cutting forces
3. Surface finish

Select the correct answer using the code given below:

- (a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

84. What are the reasons for reduction of tool life in a machining operation?

1. Temperature raise of cutting edge
2. Chipping of tool edge due to mechanical impact
3. Gradual wear at tool point
4. Increase in feed of cut at constant cutting force

Select the correct answer using the code given below

- (a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1, 2 and 4

85. Dry and compressed air is used as cutting fluid for machining:

- (a) steel (b) aluminum
(c) cast iron (d) brass

86. Consider the following statements:

Assertion (A): in a slow speed high pressure metal cutting process such as gear cutting, chlorinated or sulphonated oils are used .

Reason (R): reduction of coefficient of friction is achieved by the formation of a solid film at the rubbing interface of tool and chip.

- (a) Both A and R are individually true and R is the correct explanation of A.
- (b) Both A and R are individually true and R is not the correct explanation of A.
- (c) A is true but R is false.
- (d) A is false R is true

87. Assertion (A): For a high-speed turning of magnesium alloys, the coolant or cutting fluid preferred is water-miscible mineral fatty oil.

Reason(R): As a rule, water based oils are recommended for high-speed operations in which high temperatures are generated due to high frictional heat. Water being good coolant, the heat dissipation is efficient.

- (a) Both A and R are individually true and R is the correct explanation of A.
- (b) Both A and R are individually true and R is not the correct explanation of A.
- (c) A is true but R is false.
- (d) A is false R is true

88. Assertion (A): Oil as a cutting fluid results in a lower coefficient of friction.

Reason (R): Oil forms a thin liquid film between the tool face and chip, and it provides 'hydrodynamic lubrication'.

- (a) Both A and R are individually true and R is the correct explanation of A.
- (b) Both A and R are individually true and R is not the correct explanation of A.
- (c) A is true but R is false.
- (d) A is false R is true

89. Which of the following statements are salient features of Hydrostatic extrusion?

1. It is suitable for soft and ductile Material.
2. It is suitable for high-strength Super-alloys.
3. The billet is inserted into the extrusion chamber and the pressure is applied by a ram to extrude the billet through the die.
4. The billet is inserted into the extrusion chamber where it is surrounded by a suitable liquid. The billet is extruded through the die by applying pressure to the liquid. Select the correct answer using the code given below

- | | |
|-------------|-------------|
| (a) 1 and 3 | (b) 1 and 4 |
| (c) 2 and 3 | (d) 2 and 4 |

90. In turning, the ratio of the optimum cutting speed for minimum cost and optimum cutting speed for maximum rate of production is always

- | | |
|---------------------------------|------------------------------|
| (a) equal to 1 | (b) in the range of 0.6 to 1 |
| (c) in the ranges of 0.1 to 0.6 | (d) greater than 1 |

91. Consider the following approaches normally applied for the economic analysis of machining:

1. Maximum productions rate
2. Maximum profit criterion
3. Minimum cost criterion

The correct sequence in ascending order of optimum cutting speed obtained by these approaches is:

- | | |
|-------------|-------------|
| (a) 1, 2, 3 | (b) 1, 3, 2 |
| (c) 3, 2, 1 | (d) 3, 1, 2 |

92. Which one of the following does not affect the selection of optimum cutting speed for the minimum cost?
- (a) Labour cost (b) Machine maintenance cost
(c) Tool cost (d) Job handling cost
93. The magnitude of the cutting speed for maximum profit rate must be
- (a) in between the speeds for minimum cost and maximum production rate
(b) higher than the speed for maximum production rate
(c) below the speed for minimum cost
(d) equal to the speed for minimum cost.
94. In economics of machining, which one of the following costs remain constant?
- (a) Machining cost per piece (b) Tool changing cost per piece
(c) Tool handling cost per piece (d) Tool cost per piece
95. A diagram related to machining economics with various cost components is given above. match **List-I** (Cost element) with **List-II** (Appropriate curve) and select the correct answer using the codes given below the lists:

List-I

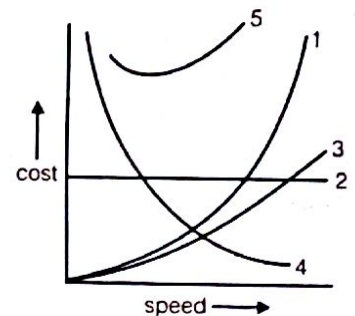
- A. Machining cost
B. Tool cost
C. Tool grinding cost
D. Non-productive cost

List-II

1. Curve-1
2. Curve-2
3. Curve-3
4. Curve-4
5. Curve-5

Codes:

	A	B	C	D
(a)	3	2	4	5
(b)	4	1	3	2
(c)	3	1	4	2
(d)	4	2	3	5



96. Consider the following statements:
- As the cutting speed increases, the cost of production initially reduces and then after an optimum cutting speed, it increases.
 - As the cutting speed increases the cost of production also increases and after a critical value it reduces.
 - Higher feed rate for the same cutting speed increases the cost of production. Which of the following statements are correct?
- (a) 1 and 3 (b) 2 and 3
(c) 1 and 4 (d) 3 only
97. In a mechanical shaper, the length of stroke is increased by:
- (a) Increasing the centre distance of bull gear and crank pin.
(b) Decreasing the centre distance of bull gear and crank pin.
(c) Increasing the length of the ram.
(d) decreasing the length of the slot in the slotted lever.
98. In a shaping operation, the average cutting is (stroke lengths S , Number of strokes per minute N , Quick return ratio R)
- (a) NSR (b) $NSR/2$
(c) $NS(1+R)$ (d) $NS(1+R)/2$

99. Which of the following are the advantages of hydraulic shaper over a mechanically driven shaper?

1. More strokes per minute can be obtained at a given cutting speed.
2. The cutting stroke has a definite stopping point.
3. It is simpler in construction.
4. Cutting speed is constant through out most of cutting stroke.

- (a) 1 and 2 (b) 1 and 4
(c) 2 and 4 (d) 1, 3 and 4

100. A 600 mm 30 mm flat surface of plate is to be finish machined on a shaper. The plate has been fixed with the 600 mm side along the tool travel direction. If the tool over-travel at each end of the plate is 20 mm, average cutting speed is 8 m/min, feed rate is 0.3 mm/stroke and the ratio of return time to cutting time of the tool is 1:2, the time required for machining will be

- (a) 8 min (b) 12 min
(c) 16 min (d) 20 min

101. Consider the following statements:

Assertion (A): internal gears are cut on a gear shaper.

Reason (R): Hobbing is not suitable for cutting internal gear.

- (a) Both A and R are individually true and R is the correct explanation of A.
(b) Both A and R are individually true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

102. A side and face cutter 125 mm diameter has 10 teeth. If operates at a cutting speed of 14 m/min with a table traverse 100 mm/min. the feed per tooth of the cutter is:

- (a) 10 mm (b) 2.86 mm
(c) 0.286 mm (d) 0.8 mm

103. A mild steel plate $400 \times 800 \times 30$ mm is to be shaped along its wider face. The ratio of return time to cutting time is 2:3 and the feed per cycle is 2 mm. tool approach and over-travel respectively are 50 mm latch and cutting speed of tool is 24 m/min. calculate the machining time required for machining the given plate with H.S.S tool:

- (a) 5 min (b) 20 min
(c) 13 min (d) 17 min

104. The rake angle in a twist drill:

- (a) varies from minimum near the dead centre to a maximum value at the periphery.
(b) is maximum at the dead centre and zero at the periphery.
(c) is constant at every point of the cutting edge.
(d) is a function of the size of the chisel edge.

105. A 31.8 mm H.S.S drill is used to drill a hole in a cast iron block 100 mm thick at a cutting speed 20 m/min and feed 0.3 mm/rev. If the over travel of drill is 4 mm and approach 9mm, the time required to drill the hole is:

- (a) 1 min 40 s (b) 1 min 44 s
(c) 1 min 49 s (d) 1 min 53 s

106. Match List-I (Mechanism) with List-II (associated function) and select the correct answer using code given below the lists:

List-I

- A. Geneva
- B. Ratchet and Pawl
- C. Whitworth
- D. Rack and shaper

List-II

- 1. Feed motion in shape gearing
- 2. Feed motion in drilling
- 3. Indexing of turret
- 4. Quick return motion in Pinion

Codes:

	A	B	C	D
(a)	3	1	2	4
(b)	1	3	2	4
(c)	2	4	1	3
(d)	3	1	4	2

107. The arm of a radial drilling machine is being raised at a speed of 3.9 m/min by a single start square threads of 6 mm pitch and 30 mm diameter. The speed of a screw:

- (a) is 650 rpm
- (b) is 180 rpm
- (c) is 130 rpm
- (d) data insufficient

108. Through holes of 10mm diameter are to be drilled in a steel plate of 20 mm thickness. Drill spindle speed is 300 rpm, feed 0.2 mm/rev and drill point angle is 120° . Assuming drill over travel of 2 mm, the time for producing a hole will be

- (a) 4 seconds
- (b) 25 seconds
- (c) 100 seconds
- (d) 110 seconds

109. The purpose of helical grooves in a twist drill is to:

- 1. improve the stiffness
- 2. save a tool material
- 3. provide a space for chip removal
- 4. provide rake angle for the cutting edge

Select the correct answer using the codes given below

- (a) 1 and 2
- (b) 2 and 3
- (c) 3 and 4
- (d) 1 and 4

110. Calculate the machining time required for drilling 4 holes of 16 mm dia latch on a flange from the following data. Flange thickness = 30 mm, cutting speed = 22 m/min and feed = 0.2 mm/rev

- (a) 1.9 min
- (b) 1.47 min
- (c) 2 min
- (d) 2.3 min

111. **Assertion (A):** For drilling cast iron, the tool is provided with a point angle smaller than that required for a ductile material.

Reason (R): Smaller point angle results in lower rake angle

- (a) Both A and R are individually true and R is the correct explanation of A.
- (b) Both A and R are individually true but R is not the correct explanation of A.
- (c) A is true but R is false.
- (d) A is false but R is true.

112. Consider the following statements:

Assertion (A): Up milling or climb milling is commonly used for machining castings and forgings.

Reason (R): Up milling can be done on universal milling machines.

- (a) Both A and R individually true and R is the correct explanation for A.
- (b) Both A and R individually true and R is not the correct explanation for A.

- (c) A is true but R is false.
(d) A is false but R is true
- Which of the following statements are correct in respect of up-milling and down-milling?
1. In up-milling the cutter rotates in a direction opposite to that of work piece travel whereas in down-milling the cutter rotates in a direction similar to that of work piece travel.
 2. In down-milling chip will be thin at the beginning and increase to a maximum at the end of the cut and reverse will be the case of a chip formed by up-milling .
 3. Down-milling is desirable with milling cutters having a high radial rake angle when compared to up-milling.
 4. Down-milling forces the work-piece against the milling table to exert more pressure while up milling tends to lift the work piece from the table.
- (a) 1, 3, 4 (b) 1, 2, 3
(c) 2, 3, 4 (d) 1, 2, 4

- 115.** A milling cutter of 70 mm diameter with 12 teeth is operating at a cutting speed of 22 m/min and a feed of 0.05 mm/tooth. The feed per minute is
- (a) 110 mm/min (b) 35 mm/min
(c) 6 mm/min (d) 60 mm/min

1. Milling with form cutter
2. Rack type gear shaper (gear planer)
3. Rotary gear shaper (gear shaper)
4. Gear hobbing

(a) 3, 2, 4, 1 (b) 2, 3, 4, 1
(c) 3, 2, 1, 4 (d) 2, 3, 1, 4

- (a) thread milling
(b) thread chasing
(c) thread cutting with single point tool
(d) thread casting

- (a) gear forming process
(b) gear generating process
(c) gear shaping process
(d) highly accurate gear producing Process

1. Face milling cutter is held on an arbor.
2. It has two rake angles-axial rake and radial rake.
3. The maximum chip thickness equals the feed per tooth.
4. The chip thickness varies from a minimum at the start of cut to a maximum at the end of cut.

Select the correct answer using the codes given below:

- | | |
|-------------|-------------|
| (a) 1 and 2 | (b) 2 and 3 |
| (c) 2 and 4 | (4) 3 and 4 |

120. Which of the following is a characteristics of the climb milling(down milling) operation?

- (a) The workpiece is fed in the opposite direction.
- (b) Forces are less.
- (c) High rigidity of the machine tool is required.
- (d) Chip thickness is maximum at the end of the cut.

121. Consider the following statements:

In up-milling process,

- 1. The cutter starts the cut from the machined surface and proceeds upwards.
- 2. the cutter starts the cut from the top surface and proceeds downwards
- 3. The job is fed in a direction opposite to that of cutter rotation.
- 4. The job is fed in the same direction as that of cutter rotation.

Of these statements:

- | | |
|-----------------------|-----------------------|
| (a) 1 & 3 are correct | (b) 1 & 4 are correct |
| (c) 2 & 3 are correct | (d) 2 & 4 are correct |

122. Internal gears can be made by:

- (a) hobbing
- (b) gear shaping with rack cutter
- (c) gear shaping with pinion cutter
- (d) gang milling

123. Which of the following motions are needed for spur gear cutting with a hob?

- 1. Rotary motion of hob.
- 2. Linear axial reciprocating motion of hob.
- 3. Rotary motion of gear blank.
- 4. Radial advancement of hob.

Select the correct answer using the codes given below:

- | | |
|----------------|----------------|
| (a) 1, 2 and 3 | (b) 1, 3 and 4 |
| (c) 1, 2 and 4 | (d) 2, 3 and 4 |

124. A straight teeth slab milling cutter of 100mm diameter and 10 teeth rotating at 200 r.p.m is used to remove a layer of 3mm thickness from a steel bar. If the table feed is 400 mm/min, the feed per tooth in this operation will be:

- | | |
|------------|------------|
| (a) 0.2 mm | (b) 0.4 mm |
| (c) 0.5 mm | (d) 0.6 mm |

125. A 60-teeth gear hobbled on a differential hobber with a two-start hob, the index change gear ratio is governed by which one of the following kinematic balance equations?

- (a) 1 revolution of gear blank = 1/60 of hob revolutions
- (b) 1 revolution of gear blank = 1/60 of hob revolutions
- (c) 1 revolution of hob = 2/60 of blank revolutions
- (d) 1 revolution of hob = 1/60 of blank revolutions

126. Consider the following motions and setting in a Hobbing machine:

- | | |
|-------------------------------------|--------------------------------------|
| 1. Hob rotation | 2. Job rotation |
| 3. Axial reciprocating job rotation | 4. Tilting of hob to its helix angle |

Which of these motions and setting in a hobbing machine are required to machine a spur gear?

- (a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 2 and 4 (d) 1, 3 and 4

127. One of the index plates of a milling machine dividing head has the following hole circles:
15 ; 16 ; 17 ; 18 ; 19 ; 20 ;

A gear wheel of 34 teeth has to be milled by simple indexing method. To machine each tooth, the index crank has to be rotated through

- (a) 17 holes in the 20 hole circle
(b) 18 holes in the 20 hole circle
(c) 1 revolution and 3 holes in 17-hole circle
(d) 1 revolution and 2 holes in 18-hole circle

128. Which one of the following processes of gear manufacture results in best accuracy of the involute gear tooth profile?

- (a) Milling (b) Hobbing
(c) Rotary gear shaper (d) Rack type gear shaper

129. Consider the following statements:

Assertion (A): Virtually all modern milling machines are capable of down-milling.

Reason(R): In down-milling the cutter tends to push the work along and lift it upward from the table. This action tends to eliminate any effect in looseness in the feed screw and nut of the milling machine table and results in smooth cut

- (a) Both A and R individually true and R is the correct explanation for A.
(b) Both A and R individually true and R is not the correct explanation for A.
(c) A is true but R is false.
(d) A is false but R is true

130. Match **List-I** (Machine tools) with **List-II** (Machine tool parts) and select the correct answer using the correct answer using the codes given below the lists :

List-I

- A. Lathe
B. Milling machine
C. Shaper
D. Drilling machine

List-II

1. Lead screw
2. Rocker arm
3. Universal indexing
4. Flute

Codes:

	A	B	C	D
(a)	4	2	3	1
(b)	1	3	2	4
(c)	4	3	2	1
(d)	1	2	3	4

131. A spur gear of 40 teeth is machined in a gear hobbing machine using double start hob cutter. The speed ratio between the hob and the blank is:

- (a) 1 : 20 (b) 1 : 40
(c) 40 : 1 (d) 20 : 1

132. The operation of producing grooves around the periphery of a cylindrical or conical work piece is called

- (a) Profile milling (b) Gang milling
(c) Saw milling (d) Helical milling

133. In a plain milling machine, the table can be moved:
(a) Longitudinally (b) Crosswise
(c) Vertically (d) All of these
134. Gear shaping is a process of manufacturing gears. Which one of the following principles is employed by it?
(a) From cutting with cutter
(b) Generating tooth from with a reciprocating cutter
(c) Generating tooth from by a rotating cutter
(d) Generating from with a reciprocating and revolving cutter.
135. Which one of the following statements is correct?
In up-milling operation, the underformed chip thickness,
(a) is zero at the start of the cut and increases to a maximum value just before the tooth disengages the workpiece.
(b) increases to the maximum value at the center of the travel and decreases towards the end of the tooth engagement
(c) has a maximum value just after the cut is started and drops to zero at the end of the cut.
(d) Remains unchanged.
136. In helical milling, the ratio of the circumference of the gear blank to the lead of the helix determines the
(a) proper speed to use
(b) proper feed and depth of cut required
(c) angle setting of the machine table
(d) gear ratio for table screw and dividing head
137. Gang milling is a:
(a) milling process for generating hexagonal surfaces
(b) process of cutting gears
(c) process in which two or more cutters are used simultaneously
(d) milling operation combined with turning
138. In the grinding wheel of A 60 G 7 B 23, B stands for
(a) resinoid bond (b) rubber bond
(c) shellac bond (d) silicate bond
139. Consider the following statements:
The set-up for internal centreless grinding consists of a regulating wheel, a pressure roll and support roll, between which the tubular workpiece is supported with the grinding wheel within the tube, wherein
1. the grinding wheel, workpiece and regulating wheel centres must line on one line.
2. the directions of rotation of workpiece and grinding wheel are same.
3. the directions of rotation of workpiece roll, support roll and regulating wheel are same.
4. the directions of rotation of grinding wheel and regulating wheel are same.
Which of these statements are correct?
(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 2 and 3 (d) 3 and 4
140. Soft material cannot be economically grounded due to:
(a) the high temperature involved (b) frequent wheel clogging
(c) rapid wheel wear (d) low workpiece stiffness

141. Specific energy requirements in a grinding process are more than those in turning for the same metal removal rate because of the:
- specific pressures between wheel and work being high.
 - size effect of the larger contact areas between wheel and work.
 - high cutting velocities.
 - high heat produced during grinding.
142. If each abrasive grain is viewed as cutting tool, then which of the following represents the cutting parameters in common grinding operations?
- Large negative rake angle, low shear angle and high cutting speed
 - Large positive rake angle, low shear angle and high cutting speed
 - Large negative rake angle, high shear angle and low cutting speed
 - Zero rake angle, high shear angle and high cutting speed.
143. A Grinding wheel of 150 mm diameter is rotating at 3000 r.p.m. The grinding speed is:
- | | |
|-------------------|-------------------|
| (a) 7.5π m/s | (b) 15π m/s |
| (c) 45π m/s | (d) 450π m/s |
144. Which of the following pairs are correctly matched?
- Drill press : Trepanning
 - Centreless grinding : through feeding
 - Capstan lathe : Ram type turret
- Select the correct answer using the codes given below:
- | | |
|-------------|----------------|
| (a) 1 and 2 | (b) 2 and 3 |
| (c) 1 and 3 | (d) 1, 2 and 3 |
145. Grinding wheel is said to be loaded when the:
- Metal particles get embedded in the wheel surface blocking the interspaces between cutting grains.
 - Bonding material comes on the surface and the wheel becomes blunt.
 - Work piece being ground comes to a stop in cylindrical grinding.
 - Grinding wheel stops because of very large depth of cut.
146. A 4 mm thick sheet is rolled with 300 mm diameter rolls to reduce thickness without any change in its width the friction coefficient at the work-roll interface is 0.1. The minimum possible thickness of the sheet that can be produced in a single pass is
- | | |
|------------|------------|
| (a) 1.0 mm | (b) 1.5 mm |
| (c) 2.5 mm | (d) 3.7 mm |
147. Which one of the following pairs of parameters and effects is not correctly matched?
- large wheel diameter... reduced wheel wear
 - large depth of cut... increased wheel wear
 - large work diameter... increased wheel wear
 - large wheel speed... reduced wheel wear
148. Consider the following reasons:
- Grinding wheel is soft
 - RPM of grinding wheel is too low
 - Cut is very fine
 - An improper cutting fluid is used

A grinding wheel may become loaded due to reasons stated at

- (a) 1 and 4 (b) 1 and 3
(c) 2 and 4 (d) 2 and 3

149. Assertion(A): The ratio of cutting force to thrust force is very high in grinding process as compared to other machining processes.

Reason(R): Random orientation and effective negative rake angles of abrasive grains increase the cutting force and adversely affect the cutting action and promote rubbing action.

- (a) Both A and R individually true and R is the correct explanation for A.
(b) Both A and R individually true and R is not the correct explanation for A.
(c) A is true but R is false.
(d) A is false but R is true

150. Match List-I with List-II and select the correct answer using the correct answer using the codes given below the lists :

List-I

- A. Quick return
B. Apron
C. Indexing
D. Regulating

List-II

1. Lathe mechanism
2. Milling Mechanism machine
3. Shaper mechanism
4. Centerless wheel grinding

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	2	3	4	1
(c)	4	2	3	1
(d)	3	1	2	4

151. Consider the following statements in respect of a grinding wheel of specifications, 51-A-36-L-7-R-23, using the standard alphanumeric codification:

1. Abrasive used in the wheel is aluminium oxide
2. The grain size of abrasive is medium
3. It has an open structure
4. It has resinoid as bonding agent

Which of these statements are correct?

- (a) 1, 2 and 3 (b) 1, 3 and 4
(c) 2, 3 and 5 (d) 1, 2 and 4

152. Which is not related term of grinding:

- (a) Truing (b) Dressing
(c) Buffing (d) Glazing

153. Which of the following materials are used in Grinding wheel?

1. Aluminium oxide
2. Cubic boron nitride
3. Silicon carbide

Select the correct answer using the codes given below:

- (a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3

154. Match **List-I** (Machine tool/cutting tool) with **List-II** (Characteristics) and select the correct answer using the codes given below the lists:

- List-I**
- A. Screw cutting lathe
 - B. Drill
 - C. End mill
 - D. Grinding wheel

- List-II**
- 1. Self locking taper
 - 2. Chasing dial
 - 3. Wiper insert
 - 4. Self relief taper
 - 5. Balance weights

Codes:

	A	B	C	D
(a)	4	5	3	2
(b)	2	1	4	5
(c)	4	1	3	5
(d)	2	5	4	1

155. Which one of the following is not a synthetic abrasive material?
- (a) Silicon Carbide
 - (b) Aluminium Oxide
 - (c) Titanium Nitride
 - (d) Cubic Boron Nitride
156. Which one of the following operation is carried out at a minimum cutting velocity if the machines are equally rigid and the tool work material are the same:
- (a) Turning
 - (b) Grinding
 - (c) Milling
 - (d) Boring
157. Consider the following statements in respect of a grinding?
1. The pitch of the grit cutting edges is larger than the pitch of the milling cutter.
 2. The cutting angles of the grits have a random geometry
 3. The size of the chip cuts is very small for grinding
- Which of these statements are correct?
- (a) 1 and 2
 - (b) 2 and 3
 - (c) 1 and 3
 - (d) 1, 2 and 3
158. Which one of the following is a single point cutting tool?
- (a) Hacksaw blade
 - (b) Milling cutter
 - (c) Grinding wheel
 - (d) Microcomputer
159. In designing the flutes of multiple-edged tools such as broaches and milling cutters, which of the factors are taken into consideration?
1. The work material
 2. The size of the tool
 3. The degree to which the chip curls
 4. The rake angle on the tool
- Select the correct answer using the codes given below:
- (a) 1, 2 and 3
 - (b) 1, 3 and 4
 - (c) 1, 2 and 4
 - (d) 2, 3 and 4

160. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

- List - I**
- A. Reaming
 - B. Counter-boring
 - C. Counter-sinking
 - D. Spot facing

List-II

1. Smoothing and squaring surface around the hole for proper seating
2. Sizing and finishing the hole
3. Enlarging the end of the hole
4. Making a conical enlargement at the end of the hole

Codes:

	A	B	C	D
(a)	3	2	4	1
(b)	2	3	1	4
(c)	3	2	1	4
(d)	2	3	4	1

161. For reaming operation of a blind hole, the type of reamer required is

- (a) straight flute reamer (b) right hand spiral fluted reamer
(c) left hand spiral fluted reamer (d) none of the above.

162. Match **List-I** (Drill bits) with **List-II** (Applications) and select the correct answer using the codes given below the

List-I

- A.** Core drill head
B. Reamer
C. Counter bore drill
D. Tap drill

List-II

1. To enlarge a hole to a certain depth so as to accommodate the bolt head screw
2. To drill & enlarge an already existing hole in a casting
3. To drill hole before making internal thread
4. To improve the surface finish and dimensions accuracy of the already drilled hole.

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	2	3	1	4
(c)	2	4	1	3
(d)	3	2	4	1

163. Consider the following statements regarding reaming process:

1. Reaming generally produces a hole larger than its own diameter.
2. Generally rake angles are not provided on reamers.
3. Even number of teeth are preferred in reamer design.

Which of these statements are correct?

- (a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

164. Which one of the following sets of tool or tools and processes are normally for making large diameter holes?

- (a) Boring tool
(b) BTA tool(Boring and Trepanning Association) and gun drill
(c) Gun drill and boring drill
(d) Boring tool and trepanning

165. Consider the following statements:

Assertion (A): No separate feed motion is required during broaching.

Reason (R): the broaching machines are Generally hydraulically operated.

- (a) Both A and R individually true and R is the correct explanation for A.
- (b) Both A and R individually true and R is not the correct explanation for A.
- (c) A is true but R is false.
- (d) A is false but R is true.

166. Match **List-I** (Machine tool) with **List-II** (Features) and select the correct answer using the codes given below the lists:

List-I

- A. Lathe
- B. Drilling machine
- C. Shaper
- D. Broaching machine

List-II

- 1. Push or pull tool
- 2. Ratchet & pawl mechanism
- 3. Dividing head
- 4. Hollow tapered spindle
- 5. Face plate

Codes:

	A	B	C	D
(a)	2	4	5	1
(b)	5	3	2	4
(c)	2	3	5	4
(d)	5	4	2	1

167. Splines are machined by

- (a) Milling
- (b) Boring
- (c) Drilling
- (d) Broaching

168. Among the following machining processes, which can be used for machining flat surfaces?

- 1. Shaping
- 2. Milling
- 3. Broaching

Select the correct answer using the codes given below:

- (a) 1 and 2
- (b) 1 and 3
- (c) 2 and 3
- (d) 1, 2 and 3

169. Match **List-I** (Cutting tools) with **List-II** (Applications) and select the correct answer using the codes given below the lists:

List-I

- A. Trepanning tool
- B. Side milling cutter
- C. Hob cutter
- D. Abrasive sticks

List-II

- 1. For surface finishing by honing
- 2. For machining gears
- 3. For cutting keyways in shafts
- 4. For drilling large diameter holes

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	4	3	2	1
(c)	1	2	3	4
(d)	4	2	3	1

170. Which one of the following processing sequences will give the best accuracy as well as surface finish?

- (a) Drilling, Reaming and Grinding
- (b) Drilling, Boring and Grinding
- (c) Drilling, Reaming and Lapping
- (d) Drilling, Reaming and Electro-plating

171. Honing process gives surface finish of what order in CLA

- (a) $10\text{ }\mu\text{m}$
- (b) $1.0\text{ }\mu\text{m}$
- (c) $0.1\text{ }\mu\text{m}$
- (d) $0.01\text{ }\mu\text{m}$

172. Given that

S = feed in mm/rev. and

R = nose radius in mm,

The maximum height of surface roughness H_{max} produced by a single-point turning tool is given by

- (a) $S^2/2R$
- (b) $S^2/4R$
- (c) $S^2/6R$
- (d) $S^2/8R$

173. Consider the following statements in relation to the unconventional machining processes:

1. Different forms of energy directly applied to work piece to have shape transformation of material removal from work surface.
2. Relative motion between the work and the tool is essential.
3. Cutting too is not in physical contact with workpiece.

Select the correct answer using the codes given below:

- (a) 1 and 2
- (b) 1, 2 and 3
- (c) 2 and 3
- (d) 1 and 3

174. Consider the following statements:

Assertion (A): Water jet machining uses high pressure and high velocity water stream which acts like a saw and cuts a narrow groove in the material

Reason (R): The force required for cutting is generated in the momentum of the water stream.

Codes:

- (a) Both A and R individually true and R is the correct explanation for A.
- (b) Both A and R individually true and R is not the correct explanation for A.
- (c) A is true but R is false.
- (d) A is false but R is true.

175. During ultrasonic machining. The metal removal is achieved by:

- (a) high frequency eddy currents
- (b) high frequency sound waves
- (c) hammering action of abrasive particles
- (d) rubbing action between tool and workpiece

176. Consider the following machining disadvantages:

1. Low metal finish
2. Poor surface cost
3. High tooling cost

Which of these disadvantages are associated with ultrasonic machine(USM)?

- (a) 1 and 3
- (b) 1 and 2
- (c) 2 and 3
- (d) 1, 2 and 3

177. Reaming is primarily used for achieving

- (a) Higher MRR
- (b) Improved dimensional tolerance
- (c) Fine surface finish
- (d) Improved positional tolerance

178. Consider the following statements:

In electrochemical grinding,

1. A rubber bounded alumina grinding wheel acts as the cathode and the workpiece as the anode.
2. A copper bounded alumina grinding wheel acts as the cathode and the workpiece as the anode.
3. Metal removal takes place due to the pressure applied by the grinding wheel.
4. Metal removal takes place due to electrolysis.

Select the correct answer using the codes given below:

- (a) 1 and 3
- (b) 2 and 4
- (c) 2 and 3
- (d) 1 and 4

179. Consider the following statements:

Assertion (A): In ECM, the shape of the cavity is the mirror image of the tool, but unlike EDM, the tool wear in ECM is less.

Reason (R): The tool in ECM is a cathode

Codes:

- (a) Both A and R individually true and R is the correct explanation for A.
- (b) Both A and R individually true and R is not the correct explanation for A.
- (c) A is true but R is false.
- (d) A is false but R is true.

180. A researcher conducts electro chemical machining (ECM) on a binary alloy (density 6000 kg/m^3) of iron (atomic weight 56, valency 2) and metal P (atomic weight 24, valency 4). Faraday's constant = 96500 coulomb/mole. Volumetric material removal rate of the alloy is $50 \text{ mm}^3/\text{s}$ at the current of 2000 A. The percentage of the metal P in the alloy is closest to

- (a) 40
- (b) 25
- (c) 15
- (d) 79

181. Which one of the following processes does not cause tool wear?

- (a) ultrasonic machining
- (b) electrochemical machining
- (c) electric discharge machining
- (d) anode mechanical machining

182. In electric discharge machining (EDM), if the thermal conductivity of tools is high and the specific heat of work piece is low, then the tool wear rate and material removal rate are expected to be respectively

- (a) high and high
- (b) low and low
- (c) high and low
- (d) low and high

183. Which statements is true for EDM

1. M.R.R increases with decreasing resistance
 2. M.R.R increases with decreasing capacitance
 3. M.R.R increases with increasing capacitance
 4. M.R.R increases with optimum spark gap then decreased with increasing spark gap.
- (a) 1, 2, 3 and 4
 - (b) 1, 2 and 3
 - (c) 1, 3 and 4
 - (d) 1, 2 and 4

184. As tool and work are not in contact in EDM process

- (a) no relative motion occurs between them
- (b) no tool wear occurs
- (c) no power is consumed during metal cutting
- (d) no force between tool and workpiece occurs

185. Match **List-I** (Unconventional machining process) with **List-II** (Basic process) and select the correct answer using the codes given below the lists:

List-I

- A. Electro polishing
- B. Electrochemical machining
- C. Abrasive jet machining
- D. Electrical discharge machining

List-II

- 1. Thermal
- 2. Mechanical
- 3. Electro-mechanical
- 4. Chemical

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	2	1	4	3
(c)	4	1	2	3
(d)	2	3	4	1

186. Match **List-I** (Machining process) with **List-II** (Associated medium) and select the correct answer using the codes given below the lists:

List-I

- A. Ultrasonic machining
- B. EDM
- C. ECM
- D. EBM

List-II

- 1. Kerosene
- 2. Abrasive slurry
- 3. Vacuum
- 4. salt solution

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	2	1	4	3
(c)	4	1	2	3
(d)	2	3	4	1

187. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I

- A. Die sinking
- B. Deburring
- C. Fine hole drilling
- D. Cutting/sharpening hard materials.

List-II

- 1. Abrasive jet machining
- 2. Laser beam machining
- 3. EDM
- 4. Ultrasonic machining
- 5. Electrochemical grinding

Codes:

	A	B	C	D
(a)	3	5	4	1
(b)	2	4	1	3
(c)	3	1	2	5
(d)	4	5	1	3

188. Match **List-I** (Machining processes) with **List-II** (Application) and select the correct answer using the codes given below the lists:

List-I

- A. EDM
B. LBM
C. USM
D. ECM

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	3	2	1	4
(c)	4	2	1	3
(d)	3	1	2	4

List-II

1. Holes and cavities in hard and brittle materials.
2. Micro-drilling and micro-welding of materials
3. Shaping of hard metals or reshaping of cemented carbide tools
4. Shaping of cemented carbide dies and punches

189. Match **List-I** (Materials) with **List-II** (Machining) and select the correct answer using the codes given below the lists:

List-I

- A. Machining of conducting materials
B. Ruby rod
C. Electrolyte
D. Abrasive slurry

Codes:

	A	B	C	D
(a)	4	2	1	3
(b)	4	2	3	1
(c)	2	4	3	1
(d)	2	4	1	3

List-II

1. ECM
2. EDM
3. USM
4. LBM

190. Typical machining operations are to be performed on hard-to-machine materials by using the process combinations

Operations

- P. Deburring (internal surface)
Q. Die sinking
R. Fine hole drilling in thin sheets
S. Tool sharpening

Processes

1. Plasma Arc machining
2. Abrasive flow machining
3. Electric discharge machining
4. Ultrasonic machining
5. Laser beam machining
6. Electrochemical machining

- (a) P-1, Q-5, R-3, S-4
(c) P-5, Q-1, R-2, S-6

- (b) P-1, Q-4, R-1, S-2
(d) P-2, Q-3, R-5, S-6

191. Which of the following components can be manufactured by powder metallurgy methods?

1. Carbide tool tips
2. Bearings
3. Filters
4. Brake linings

Select the correct answer using the codes given below:

- (a) 1,3 and 4
(b) 2 and 3
(c) 1,2 and 4
(d) 1,2,3 and 4

192. Which of the following parts can be made economically by powder metallurgy?

1. Gears
2. Automobile cylinders

3. Filters
4. Gun barrels

Select the correct answer using the codes given below:

- | | |
|-------------|-------------|
| (a) 1 and 2 | (b) 1 and 3 |
| (c) 2 and 3 | (d) 2 and 4 |

193. In powder metallurgy, the operation carried out to improve the bearing property of a bush is called :
- | | |
|------------------|--------------------|
| (a) Infiltration | (b) Impregnation |
| (c) Plating | (d) Heat treatment |

194. **Assertion(A):** close dimensional tolerances are NOT possible with isostatic pressing of metal powder in powder metallurgy technique.

Reason(R): In the process of isostatic pressing, the pressure is equal in all directions which permits uniform density of the metal powder.

- | |
|--|
| (a) Both A and R individually true and R is the correct explanation for A. |
| (b) Both A and R individually true and R is not the correct explanation for A. |
| (c) A is true but R is false. |
| (d) A is false but R is true. |

195. Consider the following processes for the manufacture of gears:

1. Casting
2. Powder metallurgy
3. Machining from bar stock
4. Closed die forging

The correct sequence in increasing order of bending strength of gear teeth is:

- | | |
|----------------|----------------|
| (a) 1, 2, 3, 4 | (b) 1, 2, 4, 3 |
| (c) 2, 1, 4, 3 | (d) 2, 1, 3, 4 |

196. **Assertion(A):** Mechanical Disintegration of a molten metal stream into fine particles by means of a jet of compressed air, is known as atomization.

Reason(R): In atomization process inert-gas or water cannot be used as a substitute for compressed air.

- | |
|--|
| (a) Both A and R individually true and R is the correct explanation for A. |
| (b) Both A and R individually true and R is not the correct explanation for A. |
| (c) A is true but R is false. |
| (d) A is false but R is true. |

197. Consider the following statements

Assertion(A): In atomization process of manufacture of metal powder the molten metal is forced through a small orifice and broken up by a stream of compressed air.

Reason(R): The metallic powder obtained by atomization process is quite resistant to oxidation

- | |
|--|
| (a) Both A and R individually true and R is the correct explanation for A. |
| (b) Both A and R individually true and R is not the correct explanation for A. |
| (c) A is true but R is false. |
| (d) A is false but R is true. |

198. Consider the following factors:

1. Size and shape that can be produced economically
2. Porosity of parts produced.
3. Available press capacity
4. High density

Which of the following limitations of powder metallurgy

- (a) 1, 3 and 4 (b) 2 and 3
(c) 1, 2 and 3 (d) 1 and 2

199. Which of the following are the limitations of metallurgy?

1. High tooling and equipment costs
2. Wastage of material
3. It cannot be automated
4. Expensive metallic powders

Select the correct answer

- (a) 1 and 2 (b) 3 and 4
(c) 1 and 4 (d) 1, 2 and 4

200. What are the advantages of powder metallurgy?

1. Extreme purity product
2. Low labour cost
3. Low equipment cost.

Select the correct answer

- (a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3

201. Match **List-I** (Task) with **List-II** (Recommendation) and select the correct answer using the codes given below the lists:

List-I

- A. Three components in a straight line should worked in one loading
B. Unloading of clamp element from jig is essential
C. Clamping of rough surface
D. Need for heavy clamping force

List-II

1. Clamp with floating pad
2. Quick action nut
3. Cam clamp
4. Equalizing clamp
5. Strap clamp

Codes:

	A	B	C	D
(a)	5	2	3	4
(b)	4	2	1	5
(c)	1	4	2	3
(d)	4	1	5	3

202. Match **List-I** (Part) with **List-II** (Method of holding) and select the correct answer using the codes given below the lists:

List-I

- A. Cylindrical parts
B. Non-cylindrical parts
C. Very complicated shapes
D. Material in bar form on small lathes

List-II

1. Circular face plate
2. Collet
3. Three jaw chuck
4. Four jaw chuck

Codes:

	A	B	C	D
(a)	3	1	4	2
(b)	2	4	1	3
(c)	3	4	1	2
(d)	2	1	4	3

203. If the diameter of the hole is subject to considerable variation, then for locating in jigs and fixtures, the type of locater used is:

- (a) conical locater (b) cylindrical locater
(c) diamond pin locater (d) V-locater

204. Compound die performs:

- (a) two or more operations at one station in one stroke
(b) two or more operations at different stations in one stroke
(c) high frequency sound waves
(d) high frequency eddy currents

205. Consider the following statements:

The cutter setting block in a milling fixture:

- Limits the total travel required by the cutter during machining.
- Takes location from the location scheme of component.

Which of these statements are correct?

- (a) only 1 (b) only 2
(c) both 1 and 2 (d) neither 1 nor 2

206. Consider the following statements:

Assertion(A): A workpiece with rough unmachined surface can be located in a jig or fixture on three supporting points.

Reason(R): Indexing is made accurate by supporting on three points

- (a) Both A and R individually true and R is the correct explanation for A.
(b) Both A and R individually true and R is not the correct explanation for A.
(c) A is true but R is false.
(d) A is false but R is true.

207. Diamond pin location is used in a fixture because:

- (a) It does not wear out
(b) it takes care of any variation in centre distance between two holes
(c) it is easy to clamp the part on diamond pins
(d) it is easy to manufacture.

208. consider the following statements:

Assertion(A): spherical washers are used to locate the job in the fixtures.

Reason(R): 3-2-1 principle should be adopted to locate the job.

- (a) Both A and R individually true and R is the correct explanation for A.
(b) Both A and R individually true and R is not the correct explanation for A.
(c) A is true but R is false.
(d) A is false but R is true.

209. Match **List-I** (Components used in jigs and fixtures) with **List-II** (Their functions) and select the correct answer using the codes given below the lists:

List-I
A. Jack pin
B. V-locater

List-II
1. To guide the drill during machining
2. For easy removal of the work piece from the jig or fixture after the machining operation is over
3. To locate the circular or semi-circular objects in a jig or fixture
4. To locate work pieces whose dimensions are subject to variations

Codes:

	A	B	C	D
(a)	3	1	4	2
(b)	3	4	2	1
(c)	4	3	1	2
(d)	4	3	2	1

210. Which of the following sets of elements are quick-acting clamping elements for fixtures?

(a) wedge and cam (b) cam and toggle
(c) toggle and wedge (d) wedge, cam and toggle

211. Match **List-I** (An element of jigs and fixtures) with **List-II** (Associating system) and select the correct answer using the codes below the lists:

List-I
A. Bush
B. Setting block
C. Diamond pin
D. V-bolck

List-II
1. Milling fixture
2. Turning fixture
3. Radial location
4. Cyclindrical location
5. Drill jigs

Codes:

	A	B	C	D
(a)	5	4	3	1
(b)	3	1	2	4
(c)	5	1	3	4
(d)	3	4	2	1

212. According to the principal of location in jigs and fixtures, how many degress of freedom are to be eliminated to have a body fixed in space

(a) 3 (b) 4
(c) 5 (d) 6

213. Lathe bed is usually made of

(a) structural steel (b) stainless steel
(c) cast iron (d) non-ferrous materials

214. Average cutting speed in machining mild steel by single point tool of H.S.S is

(a) 10 m/min (b) 20 m/min
(c) 30 m/min (d) 40 m/min

215. Tool life is said to be over if

(a) a poor surface finish is obtained
(b) sudden increase in power and cutting force with chattering take place

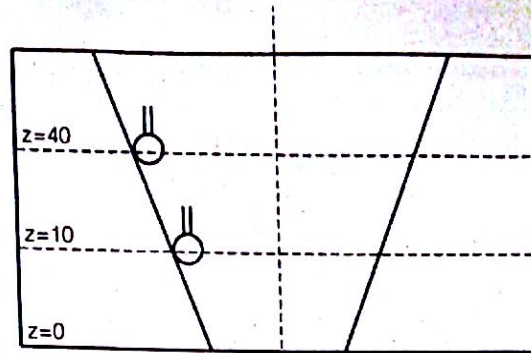
- (c) overheating and fuming due to friction start
(d) all of the above
- 216.** Tool life is most affected by
(a) cutting speed (b) tool geometry
(c) feed and depth (d) not using coolant and lubricant
- 217.** The spindle speeds of machine tools are usually designed to follow
(a) arithmetical progression (b) geometrical progression
(c) harmonical progression (d) logarithmic progression
- 218.** The spindle speeds in a cutting tool are 160, 229, 328, 496.... The next higher speed will be
(a) 642 (b) 671
(c) 695 (d) 709
- 219.** Flank wear occurs mainly on
(a) nose part, front relief face and side relief face
(b) nose part and top face
(c) cutting edges
(d) all of the above
- 220.** Which of the following properties are essential for a tool material used for high speed machining
(a) red hardness and impact resistance
(b) red hardness and wear resistance
(c) toughness and impact resistance
(d) red hardness, wear resistance and toughness
- 221.** The characteristics that enables one material to cut another is its relative
(a) toughness (b) hardness
(c) resilience (d) ductility
- 222.** Most machinable metal is one which
(a) produces discontinuous chips
(b) permits maximum metal removal per tool grind
(c) results in minimum value of shear angle
(d) all of the above
- 223.** The back rake required to machine brass by H.S.S tool is
(a) 10° (b) 5°
(c) 0° (d) -5°
- 224.** In electro-discharge machining, the tool is made of
(a) tungsten carbide
(b) properly heat treated alloy steel
(c) diamond
(d) brass or copper
- 225.** Which is false statement about electro-discharge machining
(a) it can machine very hard materials
(b) very good surface finish is obtained
(c) section to be machined should be thick
(d) metal removal rate is very slow

- 226.** In electro-chemical machining operation, the gap between tool and work is kept of the order
 (a) no gap, two are in contact with each other
 (b) 0.25 mm
 (c) 0.75mm
 (d) 1.25 mm
- 227.** In spark erosion machining process, the gap between tool and workpiece is filled with
 (a) brine solution
 (b) acid solution
 (c) a liquid dielectric
 (d) an electrolytic solution
- 228.** The machining method which uses abrasive slurry is known as
 (a) electro-discharge machining
 (b) laser machining
 (c) plasma arc machining
 (d) ultrasonic machining
- 229.** A big advantage of electro-chemical machining over electro-discharge machining is that
 (a) it is more accurate and precise
 (b) it consumes less power
 (c) its cost is low
 (d) tool wear is negligible
- 230.** Spark erosion machining method can be used for the machining
 (a) conducting materials only
 (b) non-conducting materials only
 (c) semi-conductors only
 (d) both conducting and non-conducting materials
- 231.** In spark erosion machining process, removal of metal takes places during
 (a) charging of the capacitor
 (b) discharging of the capacitor
 (c) all times
 (d) alternate cycles only
- 232.** Ultrasonic machining method is best suited for
 (a) brittle materials
 (b) stainless steels
 (c) plastics
 (d) non-ferrous alloys
- 233.** With H.S.S tools, highest cutting speed is used while machining
 (a) cast iron
 (b) mild steel
 (c) brass
 (d) aluminium
- 234.** In machining, chips break due to
 (a) ductility
 (b) toughness
 (c) work hardening
 (d) tearing of the work material
- 235.** Best coolant and lubricant for cast iron is
 (a) water soluble oils or sulphur based and mineral oils
 (b) mineral and fatty oils
 (c) soluble oils
 (d) compressed air
- 236.** 18-4-1 high speed steel contains following elements in the ratio of 18-4-1
 (a) W, Cr, V
 (b) Cr, V, W
 (c) W, Mn, Cr
 (d) W, V, Cr
- 237.** The main function of the cutting fluid is
 (a) decrease power consumption
 (b) cool the tool and workpiece
 (c) wash away the chips
 (d) all of the above
- 238.** The increase in back rake angle would affect the surface finish as follows
 (a) improve
 (b) deteriorate
 (c) unchanged
 (d) improve/deteriorate depending on materials

239. Ceramics tools are made from
 (a) tungsten oxide (b) silicon carbide
 (c) cobalt (d) aluminium oxide
240. Size of sharper is specified by
 (a) length of stroke (b) size of table
 (c) maximum size of tool (d) ratio of forward to return stroke
241. Best coolant and lubricant for aluminium is
 (a) water soluble oils or sulphur based and mineral oils
 (b) mineral and fatty oils or soluble oils
 (c) soluble oils
 (d) dry
242. Powder metallurgy techniques are used in the production of
 (a) high carbon tool steels (b) HSS tools
 (c) tungsten carbide tools (d) ceramics
243. High speed steel tool material contains carbon
 (a) 0.6-1.0% (b) 2-4%
 (c) 4-6% (d) 6-10%
244. The binding materials used in cemented carbide tools is
 (a) graphite (b) lead
 (c) cobalt (d) carbon
245. Trepanning is an operation of
 (a) cutting internal threads
 (b) producing a hole by removing metal along the circumference of a hollow cutting tool
 (c) making a cone-shaped enlargement of the end of a hole
 (d) super finishing
246. The helical grooves which extend to the full length of the drill body are called
 (a) lips (b) cutting edges
 (c) margins (d) flutes
247. For harder materials, the point angle of drill is
 (a) increased
 (b) decreased
 (c) kept at 118°
 (d) point angle has nothing to do with type of material
248. Throw away tips are used because
 (a) initial cost is low (b) tool changing is easier
 (c) regrinding is not possible (d) all of the above
249. Which is correct order for machinability of metals
 (a) magnesium alloys, grey C.I., low carbon steel, monel metal
 (b) grey cast iron, low carbon steel, magnesium alloys, monel metal
 (c) magnesium alloys, low carbon steel, grey C.I., monel metal
 (d) magnesium alloys, grey C.I., monel metal, low carbon steel
250. For particular cutting speed, the tool materials in order of tool life are
 (a) H.S.S., cemented carbides, ceramics and oxides
 (b) ceramics and oxides, cemented carbides, H.S.S.

- (c) H.S.S., ceramics and oxides, cemented carbides
(d) cemented carbides, ceramics and oxides, H.S.S.
251. Tool cutting forces, with increase in cutting speed
(a) more or less remain constant (b) increase linearly
(c) decrease linearly (d) unpredictable
252. End relief angle of a single point tool is the angle
(a) by which the face of the tool is inclined sideways
(b) by which the face of the tool is inclined towards back
(c) between the surface of the flank immediately below the point and a line drawn from the point perpendicular to the base
(d) between the surface of the flank immediately below the point and a plane at right angles to the centre line of the point of the tool
253. Cutting force and power involved in a machine tool can be measured by using
(a) pyrometer (b) comparator
(c) transducer (d) dynamometer
254. The operation of milling two sides of a workpiece simultaneously is called
(a) gang milling (b) climb milling
(c) square milling (d) straddle milling
255. The arbor of the milling machine is used to hold
(a) cutting tool (b) spindle
(c) over arm (d) mandrel
256. Feed rate in milling operation is expressed as
(a) mm/tooth (b) mm/r.p.m of the milling cutter
(c) metres/minute (d) revolution per minute
257. Negative rake is usually provided on
(a) H.S.S. tools (b) high carbon steel tools
(c) cemented carbide tools (d) all of the above
258. Side relief angle of a single point tool is the angle
(a) by which the face of the tool is inclined sideways
(b) by which the face of the tool is inclined towards back
(c) between the surfaces of the flank immediately below the point and a line drawn from the point perpendicular to the base
(d) between the surfaces of the flank immediately below the point and a plane at right angles to the centre line of the point of the tool
259. A left hand tool on lathe is used for turning in the direction
(a) from right to left (b) from left to right
(c) across the bed (d) in angular position on compound
260. Counter boring is the operation of
(a) enlarging the end of a hole cylindrically
(b) cone-shaped enlargement of the end of a hole
(c) smoothing and squaring the surface around a hole
(d) sizing and finishing a hole

261. In gang milling
- (a) several jobs can be performed in one set up
 - (b) one job is completed on several milling machines located together
 - (c) two or more cutters are mounted on the arbor and all of them remove the metal simultaneously
 - (d) all of the above
262. Spot facing is the operation of
- (a) enlarging the end of a hole cylindrically
 - (b) cone-shaped enlargement of the end of a hole
 - (c) smoothing and squaring the surface around a hole
 - (d) sizing and finishing a hole
263. Counter-sinking is the operation
- (a) enlarging the end of a hole cylindrically
 - (b) cone-shaped enlargement of the end of a hole
 - (c) smoothing and squaring the surface around a hole
 - (d) sizing and finishing a hole
264. Machinability tends to decrease with
- (a) increase in hardness and increase in tensile strength
 - (b) increase in strain hardening tendencies
 - (c) increase in carbon content, hard oxide and carbide
 - (d) decrease in grain-size
265. In the Taylor equation, value of index n is closely related to
- (a) workpiece material
 - (b) cutting tool material
 - (c) working conditions
 - (d) temperature at chip tool interface
266. Wear limit on cutting tool is of the order of
- (a) 0.3 mm
 - (b) 0.8 mm
 - (c) 1.6 mm
 - (d) 2.5 mm
267. Carbide tools wear out faster at
- (a) slow speeds
 - (b) medium speeds
 - (c) fast speeds
 - (d) very fast speeds
268. The broaching operation in which the work moves past the stationary tool is called
- (a) pull broaching
 - (b) push broaching
 - (c) surface broaching
 - (d) pot broaching
269. For tool A, Taylor's tool life exponent (n) is 0.45 and constant (K) is 90. Similarly for tool B, $n = 0.3$ and $K = 60$. The cutting speed (in m/min) above which tool A will have a higher tool life than tool B is
- (a) 26.7
 - (b) 42.5
 - (c) 80.7
 - (d) 142.9
270. A taper hole is inspected using a CMM, with a probe of 2 mm diameter. At a height, $Z = 10$ mm from the bottom, 5 points are touched and a diameter of circle (not compensated for probe size) is obtained as 20 mm. Similarly, a 40 mm diameter is obtained at a height $Z = 40$ mm. The smaller diameter (in mm) of hole at $Z = 0$ is



(a) 13.334

(c) 15.442

(b) 15.334

(d) 15.542

oooo

ANSWERS

METAL CUTTING

1. (c)	2. (b)	3. (c)	4. (c)	5. (a)	6. (b)	7. (a)
8. (b)	9. (a)	10. (a)	11. (a)	12. (b)	13. (a)	14. (d)
15. (a)	16. (a)	17. (d)	18. (a)	19. (a)	20. (b)	21. (d)
22. (b)	23. (c)	24. (b)	25. (d)	26. (a)	27. (b)	28. (a)
29. (a)	30. (b)	31. (b)	32. (a)	33. (d)	34. (a)	35. (c)
36. (b)	37. (a)	38. (a)	39. (b)	40. (d)	41. (a)	42. (c)
43. (b)	44. (b)	45. (c)	46. (d)	47. (b)	48. (a)	49. (d)
50. (c)	51. (b)	52. (c)	53. (c)	54. (b)	55. (a)	56. (c)
57. (c)	58. (c)	59. (b)	60. (b)	61. (b)	62. (d)	63. (a)
64. (a)	65. (b)	66. (c)	67. (d)	68. (a)	69. (a)	70. (b)
71. (d)	72. (a)	73. (c)	74. (a)	75. (b)	76. (a)	77. (c)
78. (d)	79. (a)	80. (b)	81. (b)	82. (c)	83. (a)	84. (a)
85. (c)	86. (a)	87. (d)	88. (c)	89. (d)	90. (b)	91. (c)
92. (a)	93. (a)	94. (c)	95. (b)	96. (a)	97. (a)	98. (d)
99. (c)	100. (b)	101. (b)	102. (c)	103. (c)	104. (a)	105. (d)
106. (d)	107. (a)	108. (b)	109. (c)	110. (b)	111. (d)	112. (d)
113. (a)	114. (b)	115. (d)	116. (d)	117. (b)	118. (b)	119. (b)
120. (c)	121. (a)	122. (c)	123. (a)	124. (a)	125. (c)	126. (a)
127. (c)	128. (b)	129. (c)	130. (b)	131. (d)	132. (d)	133. (d)
134. (d)	135. (a)	136. (c)	137. (c)	138. (a)	139. (d)	140. (b)
141. (b)	142. (a)	143. (d)	144. (a)	145. (a)	146. (c)	147. (d)
148. (c)	149. (d)	150. (d)	151. (a)	152. (c)	153. (a)	154. (b)
155. (b)	156. (c)	157. (b)	158. (a)	159. (b)	160. (d)	161. (a)
162. (c)	163. (b)	164. (d)	165. (c)	166. (d)	167. (d)	168. (d)
169. (b)	170. (c)	171. (d)	172. (d)	173. (d)	174. (a)	175. (c)
176. (a)	177. (b)	178. (b)	179. (b)	180. (b)	181. (b)	182. (d)

183. (c)	184. (d)	185. (a)	186. (b)	187. (c)	188. (c)	189. (d)
190. (d)	191. (d)	192. (b)	193. (b)	194. (c)	195. (a)	196. (b)
197. (c)	198. (c)	199. (c)	200. (b)	201. (d)	202. (d)	203. (a)
204. (a)	205. (c)	206. (c)	207. (b)	208. (d)	209. (c)	210. (c)
211. (c)	212. (c)	213. (c)	214. (c)	215. (d)	216. (a)	217. (b)
218. (d)	219. (a)	220. (d)	221. (b)	222. (b)	223. (c)	224. (d)
225. (c)	226. (b)	227. (c)	228. (d)	229. (d)	230. (a)	231. (b)
232. (a)	233. (d)	234. (c)	235. (d)	236. (a)	237. (d)	238. (a)
239. (d)	240. (a)	241. (a)	242. (c)	243. (a)	244. (c)	245. (b)
246. (d)	247. (a)	248. (d)	249. (a)	250. (b)	251. (c)	252. (c)
253. (d)	254. (d)	255. (a)	256. (a)	257. (c)	258. (d)	259. (b)
260. (a)	261. (c)	262. (c)	263. (b)	264. (d)	265. (b)	266. (a)
267. (b)	268. (d)	269. (a)	270. (a)			

Metal Forming

Forming is the process in which the desired size and shape are obtained through the plastic deformation of a material. The stresses induced during the process are greater than the yield strength, but less than the fracture strength, of the material. Forming is developing very fast because metal forming operations such as forging, rolling, drawing, etc., are capable of yielding high productivity compared to other metal working techniques. Metal forming is one of the most important steps in manufacturing of a large variety of products. It involves in obtaining desired shape and size by subjecting the material to large plastic deformation. Equally important is the control of mechanical properties and product quality. Metal forming or metal working processes are divided into two categories i.e. bulk forming and sheet metal forming. Bulk forming refers to processes like forging, rolling, extrusion etc. where there is a controlled plastic flow of material into useful shapes. Forming can be classified in to these three categories:

Cold Working $< 0.4 T_m$

Warm Working $0.4 - 0.6 T_m$

Hot Working $> 0.6 T_m$

where T_m is melting point of material in Kelvin

Cold working is, when the material is deformed below recrystallization temperature. If the working temperature is higher than the recrystallization is called hot working, if the material is at recrystallization temperature it is called warm working. Following are the characteristics of metal working:

1. Due to work hardening cold working products will be stronger than hot worked products. In hot working since there is scale formation surface finish will be better in cold working.
2. Since in cold working there will not be any shrinkage so better dimensional accuracy will be produced.
3. For hard and brittle materials excessive load will appear in the cold working so the process will be uneconomical and hot working is used for such materials
4. Due to excessive cold working defects like internal cracks may appear in the workpiece. Also the process is limited to low strength ductile materials only otherwise the power requirement goes up.

The main objective of metal working analysis is to predict the stresses acting during metal deformation and consequently the forces which must be applied. The working load determines the power requirements and the size of the equipment necessary to perform a particular operation. Measurement of forces also, gives an indication of the efficiency of the process.

In uniaxial tension or pure compression the yield stress can easily be defined and its value read from the stress strain diagram of the material.

1. If the material behaves like that of the elastic-plastic then yield strength can be considered as mean flow stress or nominal stress or the stress at which the material begins to flow and take the shape of

dies. If the material behaves like elastic-work hardening, then average flow stress is taken as nominal stress (σ_0) and it can be calculated as under:

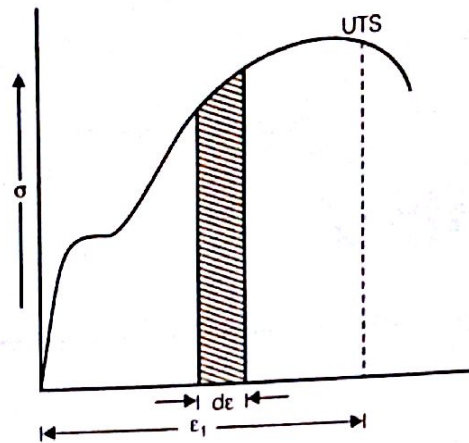


Fig 5.1 : Wire drawing process

$$\sigma_{fm} = \frac{1}{\epsilon_1} \int_0^{\epsilon_1} \sigma_f d\epsilon = \frac{1}{\epsilon_1} \int_0^{\epsilon_1} K\epsilon^n d\epsilon \quad (\text{since } \sigma_{fm} = K\epsilon^n)$$

$$\sigma_{fm} = \frac{1}{\epsilon_1} \left[\frac{K\epsilon^{n+1}}{n+1} \right]_0^{\epsilon_1} \quad (\sigma_{fm} \text{ is mean flow stress})$$

$$\sigma_0 = \sigma_{fm} = \frac{K\epsilon_1^n}{n+1}$$

In this analysis elastic strains are neglected as compared to plastic strains. At this point it is important to understand the difference between plane strain (von-mises) and the plane stress (tresca hypothesis). If the deformation of material is:

- Everywhere parallel to a given plane.
- Independent of Z-direction.

Then the deformations are considered as plane strain. If the deformations are not restricted in Z- directions, it is called plane stress case. E.g wire drawings, extrusion forging in rectangular dies are plane strain case. The stress tensor can be broken into two parts as under.

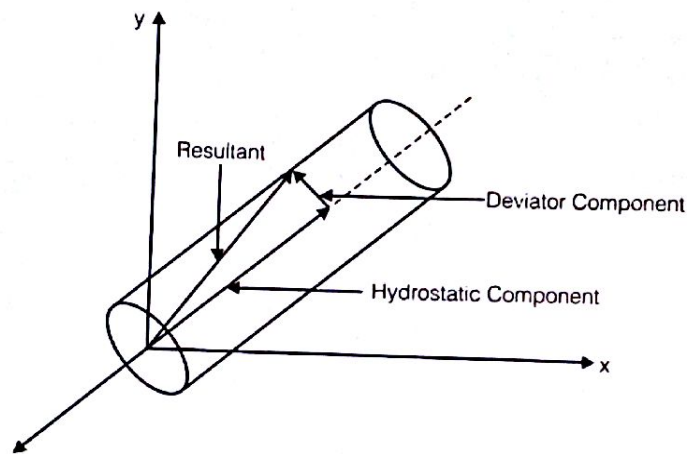
$$\begin{bmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{bmatrix} \Rightarrow \begin{bmatrix} \sigma_{xx} - \sigma & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} - \sigma & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} - \sigma \end{bmatrix} + \begin{bmatrix} \sigma & 0 & 0 \\ 0 & \sigma & 0 \\ 0 & 0 & \sigma \end{bmatrix}$$

Where $\begin{bmatrix} \sigma & 0 & 0 \\ 0 & \sigma & 0 \\ 0 & 0 & \sigma \end{bmatrix} \Rightarrow \text{hydrostatic component}$

$$\begin{bmatrix} \sigma_{xx} - \sigma & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} - \sigma & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} - \sigma \end{bmatrix} \Rightarrow \text{Deviator component}$$

Von-Mises [plane strains] :

In plane strain case it can be represented by a von-mises cylinder. Hydrostatic stress acts along the centre of cylinder and deviator component acts in the radial direction. Hydrostatic component does not cause any plastic deformation. So if a major portion of the stress is converted into hydrostatic component, ductility of the material improves. So hydrostatic pressure is applied on the material in deep drawing operation and this concept is used in hydrostatic extrusion to draw hard and brittle materials. As long as deviator component is within the cylinder, the deformation of the material is within the elastic region. Plastic deformation begins as soon as the resultant stress reaches the surface of the cylinder. Plane stress or Tresca hypothesis is represented by hexagon cylinder and hexagon will be inside the circle if yield tensile strength is taken to be same in both the cases. Hexagon will be outside the von-mises circle when yield shear strength is taken to be same in both the cases.

**Fig 5.2 : Wire drawing process**

For plane strain case

$\epsilon_z = \frac{\partial w_z}{\partial z} = 0$ this corresponds to $\sigma_{zz} - \sigma = 0$ where

σ = Hydrostatic pressure

$$\sigma = \frac{\sigma_{xx} + \sigma_{yy} + \sigma_{zz}}{3}$$

$$\sigma_{zz} - \left(\frac{\sigma_{xx} + \sigma_{yy} + \sigma_{zz}}{3} \right) = 0$$

$$\sigma_{zz} = \frac{\sigma_{xx} + \sigma_{yy}}{2}$$

Putting this value in Von-mises hypothesis we get

$$(\sigma_{xx} - \sigma_{yy})^2 + (\sigma_{yy} - \sigma_{zz})^2 + (\sigma_{zz} - \sigma_{xx})^2 = 6K'^2$$

K' = yield shear strength

$$(\sigma_{xx} - \sigma_{yy})^2 + \left(\sigma_{yy} - \left(\frac{\sigma_{xx} + \sigma_{yy}}{2} \right) \right)^2 + \left(\left(\frac{\sigma_{xx} + \sigma_{yy}}{2} \right) - \sigma_{xx} \right)^2 = 6K'^2$$

$$(\sigma_{xx} - \sigma_{yy})^2 + \left(\frac{\sigma_{yy} - \sigma_{xx}}{2} \right)^2 + \left(\frac{\sigma_{yy} - \sigma_{xx}}{2} \right)^2 = 6K'^2$$

$$\frac{3}{2}(\sigma_{xx} - \sigma_{yy})^2 = 6K'^2$$

$$(\sigma_{xx} - \sigma_{yy})^2 = 4K'^2$$

or writing in terms of principal stresses σ_1 and σ_2 we get

$$\frac{\sigma_1 - \sigma_2}{2} = K'$$

To have a relationship between yield shear strength (K') and nominal stress (σ_0), let us take uniaxial tensile test case. Putting its conditions in von-mises hypothesis we get,

$$2\sigma_{xx}^2 = 6K'^2$$

$$2\sigma_0^2 = 6K'^2$$

$$K' = \frac{\sigma_0}{\sqrt{3}}$$

So,

$$\frac{\sigma_x - \sigma_y}{2} = \frac{\sigma_0}{\sqrt{3}}$$

$$\begin{aligned} \sigma_1 - \sigma_2 &= \frac{2}{\sqrt{3}} \sigma_0 \\ &= 1.15 \sigma_0 \end{aligned}$$

For plane stress case :

$$\sigma_1 - \sigma_2 = 2K' \text{ (Tresca hypothesis)}$$

From uniaxial tensile test we get

$$\sigma_0 = 2K'$$

$$K' = \frac{\sigma_0}{2}$$

So

$$\sigma_1 - \sigma_2 = \sigma_0 \text{ for plane stress}$$

$$K' = \frac{\sigma_0}{2}$$

If flow is restricted in one direction then it is plane strain. If there is no restriction in any direction to flow then it is plane stress.

5.1 WIRE DRAWING

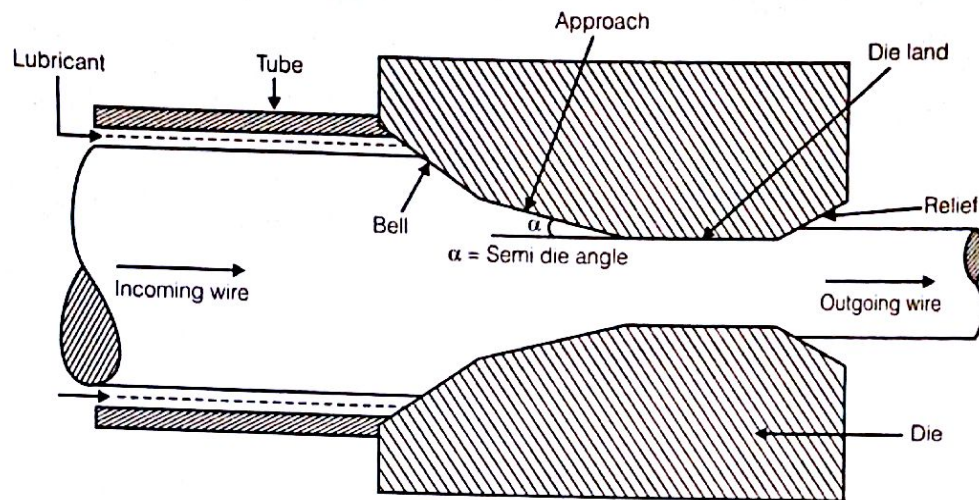


Fig 5.3 (a) : Wire drawing process

A circular cross section billet is reduced in diameter and increased in length by pulling through a conical die of semi angle. The theory developed has some assumptions:

- A uniform state of stress is assumed to prevail at all points at a plane normal to the axis.
- The redundant work is negligible.
- A cylindrical state of stress is assumed to exist within the contact zone. The axial stress and die pressure can be assumed to be principle stresses.

Before wire enters into the die it should be given a twist or bend to remove oxide layer from it, the wire is then dipped into a lubricant. As the wire is entering into the bell section of die it will be coated with a layer of lubricant. As lubricant hits the die, it loses all its momentum which converts into pressure which enables the lubricant to enter into the deformation zone. For heavy reduction solid lubricants like soap powder, Aluminium, graphite, lime etc. are used. It produces dull surface. Liquid lubricants like soap solution, oil etc. gives bright finish. In the initial stages wire comes in contact with the bell, the shape of the bell causes the hydrostatic pressure to increase and promotes the flow of lubricant into the die. Actual deformation of the material takes place in the approach section of die. By providing die land, although the drawing forces will increase but it is required for die stability.

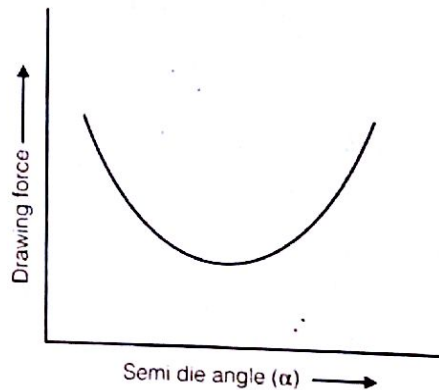


Fig 5.3 (b) : Wire drawing process

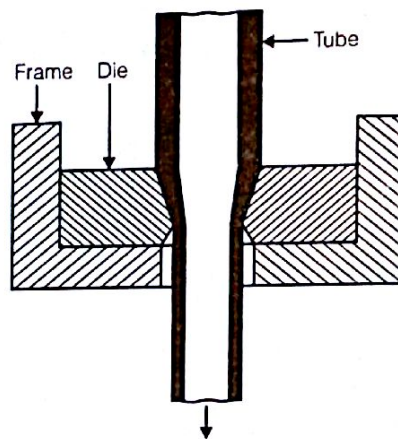
By increasing the semi die angle the contact length between material and die decreases. This decreases the friction and hence drawing forces decrease. When the semi die angle increases beyond a certain value the dead metal zone starts forming within the metal flow region. These regions not only create an obstacle in the metal flow but also start moving in the backward direction. This increases the drawing force requirement. Dead metal zone produces a bright finish to the deformed material. Towards the end, some back relief is provided for the elastic recovery.

5.1.1 Defects of wire drawing

1. If removal of oxide from the wire is not proper, these impurities will percolate down and settles at the centre which produces centre line cracks. If the lubricating film breaks over the surface it leads to surface cracks.
2. Another type of defect is called seams, which are longitudinal scratches or folds in the material. Seams may open up during the operation and they can cause serious quality control problems in production.
3. In cold drawn products there will be residual stresses. These residual stresses can be significant in causing stress corrosion cracking of the part over a period of time.

5.2 TUBE DRAWING

In the tube sinking, deformation is carried out without any support so neither there is a control of out going tube thickness nor control over the surface finish.



For tube sinking operation

(i) $\frac{t_1}{R} \leq 0.33$ when $t_2 > t_1$

(ii) $\frac{t_1}{R} > 0.33$ when $t_2 < t_1$

Where t_1 and t_2 are the incoming and outgoing tube thickness respectively.

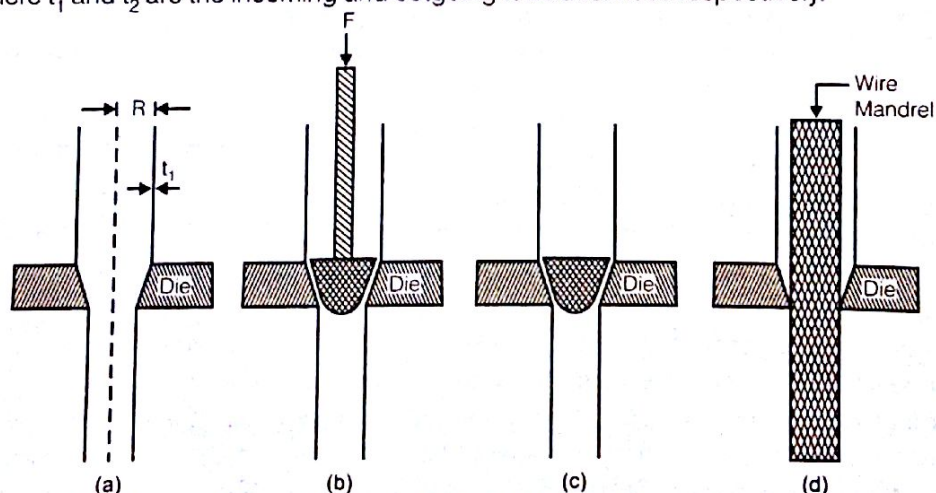


Fig 5.4 (a) : (a) Tube sinking operation. (b) tube drawing with fixed mandrel
(c) Tube drawing with floating mandrel (d) tube drawing with moving mandrel

In case of floating mandrel there is a partial control over plastic deformation at the inside so surface will be better but dimensions will not be controlled. In the case of fixed mandrel by carrying the load on the mandrel thickness of tube can be controlled.

In case of tube drawing with moving mandrel the speed of wire is equal to the velocity of out going tube so at the entry to the die, velocity of wire will be higher than the velocity of incoming tube. So relative to wire (in the wire region) tube is going in the backward direction, so friction will appear in the forward direction. On the interface between the tube and die, friction appears in the backward direction. These oppositely acting frictions cancel each other. So for the same amount of reduction drawing pressure will be lowest in case of moving mandrel. So heavy reductions are possible.

5.3 EXTRUSION

Extrusion is defined as the process of pushing the heated billet of metal through an orifice provided into a die, thus forming an elongated part of uniform cross section corresponding to the shape of the die orifice. The pressure is applied hydraulically or mechanically. Intricate shapes in long lengths can be produced by hot extrusion. Depending on the ductility of the material, extrusion may be carried out at room or at elevated temperature. Because a chamber is involved each billet is extruded individually and thus extrusion is a batch or semicontinuous process.

Typical products made from extrusion are railings for sliding doors, tubing for various cross sections, structural and architectural shapes and doors and window frames.

5.3.1 Forward Extrusion or Direct Extrusion

The raw material used is a billet. Billet is heated to its forging temperature and fed into the machine chamber. In this forward extrusion piston and out going material moves in the same direction. Pressure is applied to the billet, forcing the material through the die. In forward direction since billet moves inside the drum so pressure required in overcoming the friction will be more. The length of the extruded part depends on the size of the billet and cross section area of the die.

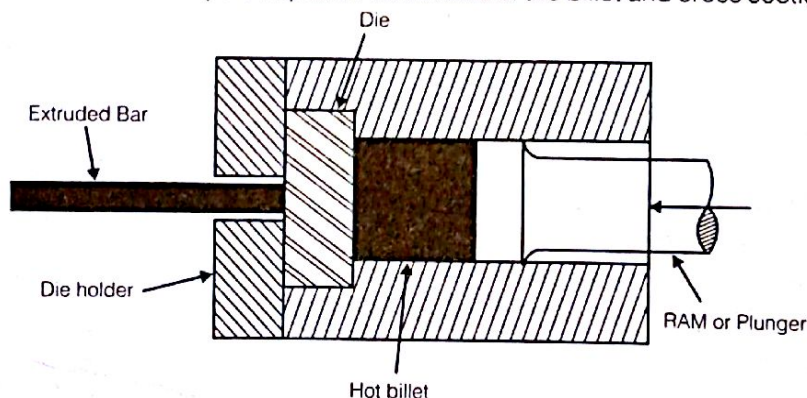


Fig 5.5 (a) : Forward extrusion

A typical sequence of operations for the forward extrusion of a solid section is as follows:

1. The heated billet and the dummy block are loaded into the container
2. The billet is extruded by the force of the ram being pushed against it. This upsets the billet, then forces the metal to flow through the die. During extrusion, a thin shell of material may be left on the container walls. Extrusion is halted in order to leave a thin disk of material (butt) in the container
3. The container is separated from the die, the extruded section with the butt, and the dummy block

4. The discard (butt) is sheared off
5. The shear die, the container, and the ram are returned to their initial (loading) positions

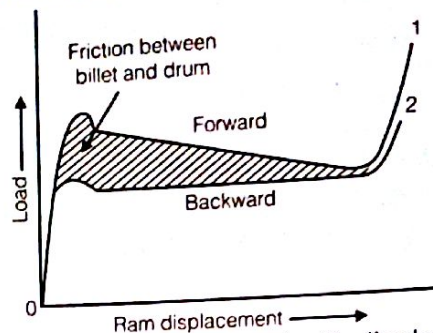


Fig. 5.5 (b) : Variation of load with displacement in forward and backward extrusion

Typical load versus ram displacement curves show that the load in forward extrusion initially increases very rapidly as the billet upsets to fill the container. This is followed by a further increase in pressure, and extrusion begins. A somewhat cone-shaped deformation zone then develops in front of the die aperture. After the maximum load has been reached, the extrusion pressure falls as the billet length decreases until a minimum is reached, then rapidly increases again. This last pressure increase occurs because only a disk of the billet remains and the metal must flow radially toward the die aperture. Resistance to deformation increases considerably with decreasing thickness.

5.3.2 Backward Extrusion or Indirect Extrusion

In backward extrusion the die is placed in the piston, so outgoing material will come out in the opposite direction to that of the piston. In this process the billet does not move inside the chamber. So there is no friction between the billet and the drum. So less force is required in this method in comparison to the direct extrusion. A more complicated type of equipment is required because the plunger becomes weak due to the reduction in its effective area of cross-section and ductility is experienced in supporting the overhanging extruded part.

The sequence of operations for the backward extrusion of a solid section is as follows:

1. The die is inserted into the press
2. The billet is loaded into the container
3. The billet is extruded, leaving a butt
4. The die and the butt are separated from the section

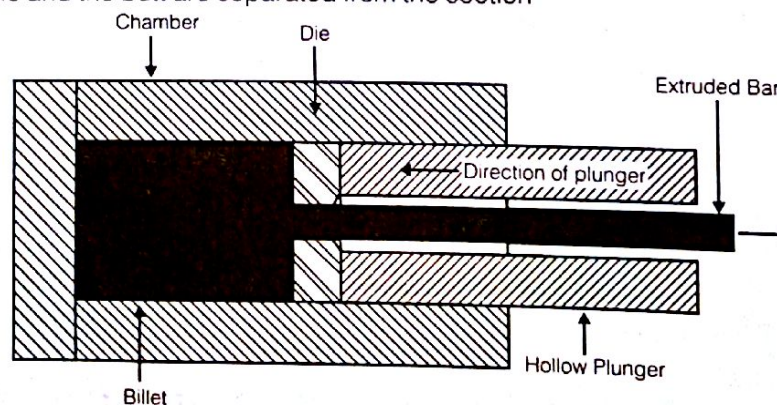


Fig 5.5 (c) : Backward extrusion

Backward extrusion offers a number of advantages, as follows:

1. A 25 to 30% reduction in maximum load relative to direct extrusion
2. Extrusion pressure is not a function of billet length, because there is no relative displacement between the billet and the container. Therefore, billet length is not limited by the load required for this displacement but only by the length and stability of the hollow stem needed for a given container length
3. No heat is produced by friction between the billet and the container; consequently, no temperature increase occurs at the billet surface toward the end of extrusion, as is typical in the direct extrusion of aluminum alloys. Therefore, in backward extrusion, there is a lesser tendency toward cracking of the surfaces and edges, and extrusion speeds can be significantly higher
4. The service life of the tooling is increased, especially that of the inner liner, because of reduced friction and temperatures

The disadvantage of backward extrusion is that impurities or defects on the billet surface affect the surface of the extrusion and are not automatically retained as a shell or discard in the container. As a result, machined billets are used in many cases. In addition, the cross-sectional area of the extrusion is limited by the size of the hollow stem.

5.3.3 Hydrostatic Extrusion

In hydrostatic extrusion the billet is smaller in diameter than the chamber, which is filled with a fluid and the pressure is transmitted to the billet by a ram. Billet does not come in contact with the piston and the material is deformed due to development of hydrostatic pressure within the fluid. Since hydrostatic pressure increases the ductility, very good quality products can be extruded by this process. In this process large hydrostatic pressure applied to the billet, the product in the receiving chamber is maintained under a lower pressure. There is no friction to overcome along the container walls.

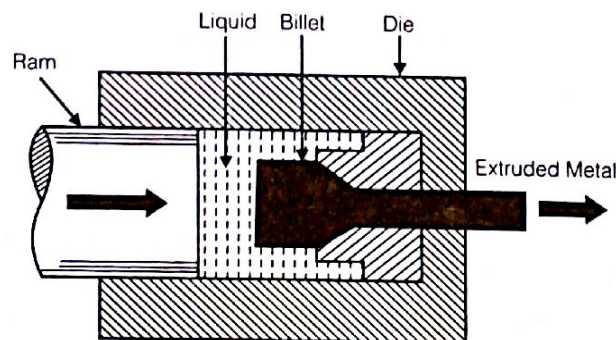


Fig. 5.5 (d) : Hydrostatic extrusion

In Hydrostatic extrusion, the billet in the container is extruded through the die by the action of a liquid pressure medium rather than by direct application of the load with a ram. The process of pure hydrostatic extrusion differs from conventional extrusion in that the billet is completely surrounded by a fluid, which is sealed off and is pressurized sufficiently to extrude the billet through the die. Hydrostatic extrusion can be done hot, warm, or cold and can be used to extrude brittle materials that cannot be processed by conventional extrusion. Hydrostatic extrusion also allows greater reductions in area (higher extrusion ratios) than either cold or conventional hot extrusion. The primary advantages of simple hydrostatic extrusion over conventional hot or cold extrusion methods are:

1. There is no friction between the billet and the container. Therefore, the pressure at the beginning of extrusion is much lower, and billets of any length can theoretically be extruded
2. Friction at the die can be significantly reduced by a film of pressurized lubricant between the deforming metal and the die surface
3. The lower extrusion pressures and the reduced die friction of hydrostatic extrusion allow the use of either higher extrusion ratios or lower extrusion temperatures
4. The uniform hydrostatic pressure in the container means that billets do not have to be straight; coiled wire can also be extruded

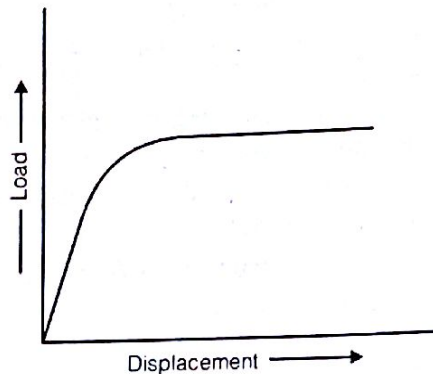


Fig. 5.5 (e) : Hydrostatic Extrusion

Limitations of the hydrostatic extrusion process include :

1. Containment of the fluid under high pressure (up to 2 GPa, or 290 ksi) requires reliable seals between the container bore surface and both the ram and die. The technology required to achieve dependable seals at these points is widely available. However, also sealing between the billet nose and the die can easily be achieved by chamfering or tapering the billet nose to match the entry angle of the die
2. In addition to being tapered to match the die opening angle, the billet is also usually machined all over to remove surface defects that would otherwise reappear on the extruded product. This is especially true when cast billets are being used.

5.3.4 Impact extrusion

This comes under the mostly cold extrusion process. In impact extrusion a heavy punch is allowed to fall over the material and material takes the shape of the die by flowing in the clearance between punch and die. Collapsible tubes can be made by this. This is used to make collapsible tubes of soft alloys such as tooth paste containers. This process is limited to soft and ductile materials.

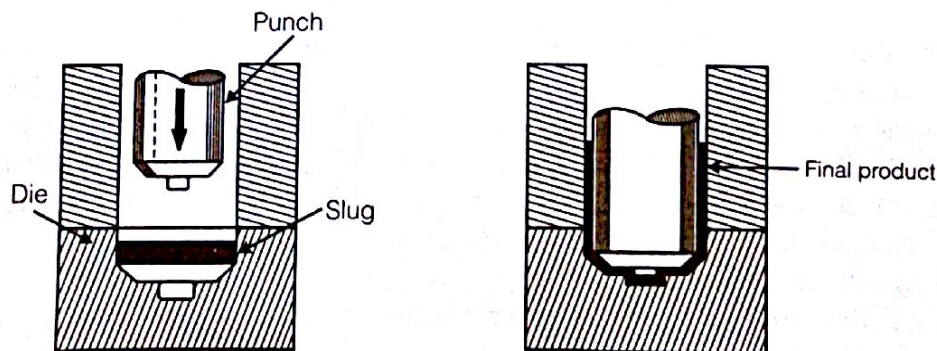


Fig 5.5 : (f) Impact extrusion

5.4 ANALYSIS OF WIRE DRAWING AND EXTRUSION

(A) Johnson's Equation

$$\sigma_d = \sigma_0 [a + b \ln R]$$

where a , b are Johnson's constant, σ_0 is nominal stress and R is extrusion ratio.

$$R = \text{Extrusion ratio} = \frac{A_i}{A_f} \quad (A_i \text{ is initial area and } A_f \text{ is final area})$$

For hot extrusion

$$\sigma_d = K_1 \ln R$$

K_1 = Extrusion constant which depends upon temperature.

Example : 5.1

A cylindrical billet of 40mm diameter and 100mm length is reduced by backward extrusion to a 15 mm diameter. If the Johnson's equation has $a = 0.8$ $b = 1.5$ and strength coefficient of material 750 MPa strain hardening coefficient $n = 0.15$ Determine

(i) Extrusion ratio (ii) true strain (iii) Extrusion strain (iv) Ram force

Solution :

Given data

$$\begin{aligned} a &= 0.8 \\ b &= 1.5 \\ K &= 750 \text{ MPa} \\ n &= 0.15 \end{aligned}$$

$$\frac{\pi}{4} D_i^2 L_i = \frac{\pi}{4} D_f^2 L_f$$

$$(40)^2(100) = (15)^2 L_f$$

$$\Rightarrow L_f = 711.11 \text{ mm}$$

$$\text{Extrusion strain} = e = \frac{L_f - L_i}{L_i}$$

$$= \frac{711.11 - 100}{100} = 6.11$$

$$\text{True strain} = \epsilon = \ln[1+e] = \ln[1 + 6.11] = 1.96$$

$$\text{Extrusion ratio} = R = \frac{A_i}{A_f} = 7.11$$

$$\sigma_0 = \frac{K\epsilon^n}{n+1} = \frac{750(1.96)^{0.15}}{1.15} = 721 \text{ MPa}$$

So,

$$\sigma_d = \sigma_0 [a + b \ln R] = 721[0.8 + 1.5 \ln 7.11] = 2698.16 \text{ MPa}$$

$$\text{Ram force} = \sigma_d \times \frac{\pi}{4} [D_i^2 - D_f^2] = 2.9 \text{ MN}$$

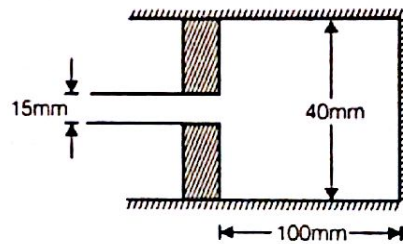


Fig 5.6

(B) Slab Method

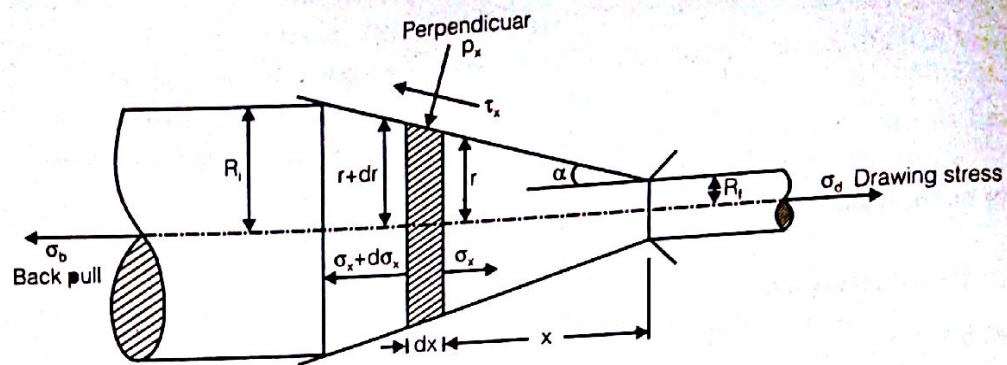


Fig 5.7 (a) : Stresses in drawing

Mass in x direction

$$\Rightarrow (\sigma_x + d\sigma_x) \pi (r + dr)^2 - \sigma_x \pi r^2 + \tau_x \cos \alpha \left(\frac{2\pi r dx}{\cos \alpha} \right) + p_x \sin \alpha \left(\frac{2\pi r dx}{\cos \alpha} \right) = 0 \quad \dots(1)$$

$$\Rightarrow \pi \left[\sigma_x r^2 + \sigma_x d^2 r + 2r dr d\sigma_x + d\sigma_x r^2 + d\sigma_x dr^2 + 2r dr d\sigma_x \right]$$

$$-\sigma_x \pi r^2 + \tau_x \cos \alpha \left(\frac{2\pi r dx}{\cos \alpha} \right) + p_x \sin \alpha \left(\frac{2\pi r dx}{\cos \alpha} \right) = 0 \quad (2)$$

Neglecting smaller terms and divide by $r^2 dr$

$$\frac{d\sigma_x}{dr} + \frac{2\sigma_x}{r} + \frac{2p_x \tan \alpha}{r} \frac{dx}{dr} + \frac{2\tau_x}{r} \frac{dx}{dr} = 0$$

from triangle; $\frac{dx}{dr} = \cot \alpha$; and $\tau_x = \mu p_x$

$$\text{So } \frac{d\sigma_x}{dr} + \frac{2\sigma_x}{r} + \frac{2p_x}{r} + \frac{2\mu p_x \cot \alpha}{r} = 0$$

Assuming σ_x and p_x are the principle stresses.

$$\sigma_x + p_x = 2K'$$

$$\frac{d\sigma_x}{dr} + \frac{2[2K']}{r} + \frac{2\mu \cot \alpha}{r} (2K' - \sigma_x) = 0$$

$$\frac{d\sigma_x}{dr} = -\frac{2}{r} [2K' + \mu \cot \alpha [2K' - \sigma_x]]$$

let $\mu \cot \alpha = B$

$$\frac{d\sigma_x}{dr} = -\frac{2}{r} [2K' + B[2K' - \sigma_x]]$$

$$\int \frac{d\sigma_x}{[2K' + B[2K' - \sigma_x]]} = \int -\frac{2}{r} dr$$

$$\frac{-1}{B} \ln [2K' + B[2K' - \sigma_x]] = -2 \ln r + C_1 \quad \dots(3)$$

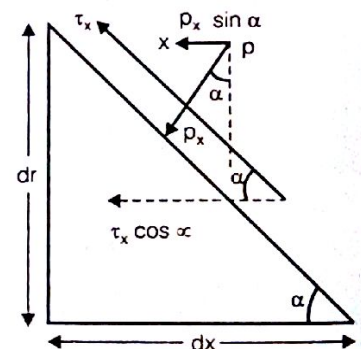


Fig 5.7 (b)

Case II : Tube drawing with floating mandrel

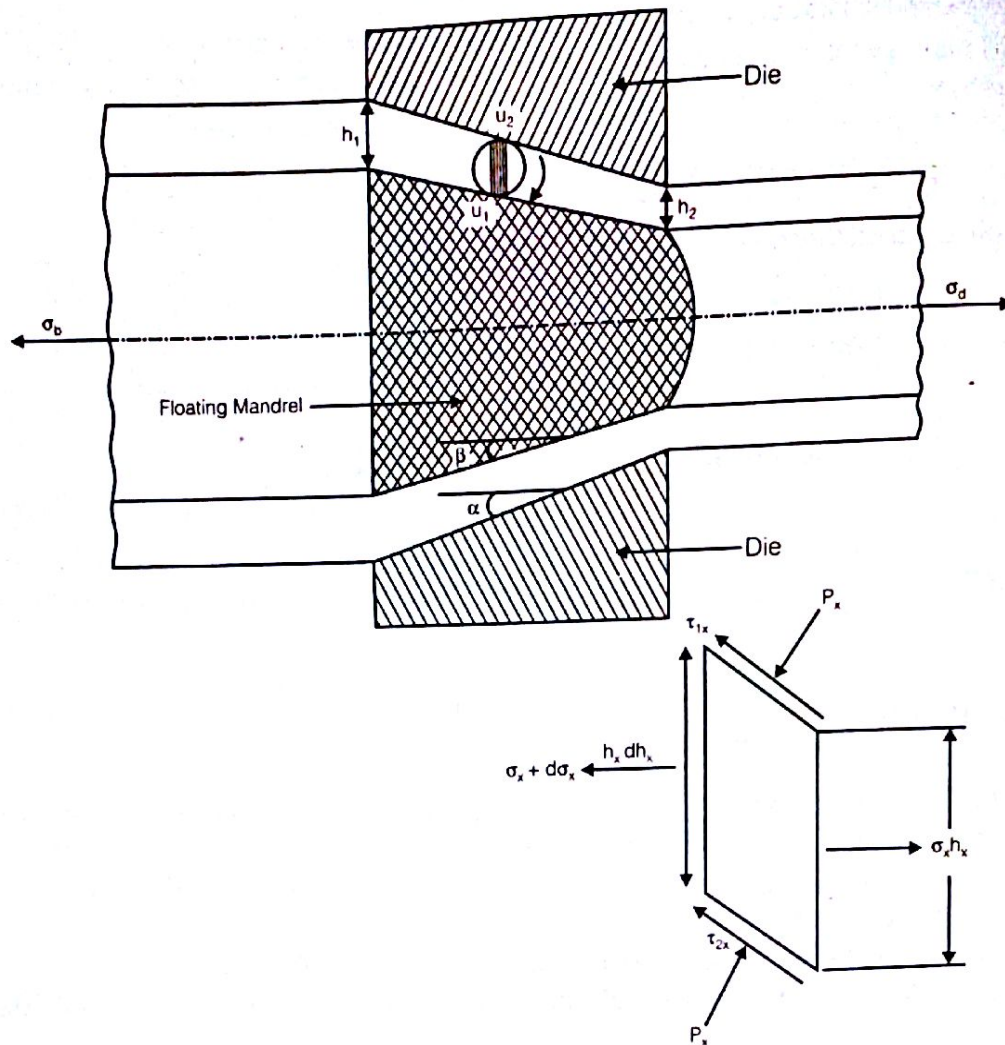


Fig 5.9 : Mandrel Analysis

$$\sigma_d = \left(\frac{2\sigma_0}{\sqrt{3}} \right) \left(\frac{1+B_1}{B_1} \right) \left[1 - \left(\frac{h_2}{h_1} \right)^{B_1} \right] + \sigma_b \left(\frac{h_2}{h_1} \right)^{B_1} \quad \dots(7)$$

where

$$B_1 = \frac{\mu_1 + \mu_2}{\tan \alpha - \tan \beta}$$

Case III : Tube drawing with moving mandrel

Similar extrusions can be written as

$$\sigma_d = \left(\frac{2\sigma_0}{\sqrt{3}} \right) \left(\frac{1+B_2}{B_2} \right) \left[1 - \left(\frac{A_2}{A_1} \right)^{B_2} \right] + \sigma_b \left(\frac{A_2}{A_1} \right)^{B_2} \quad \dots(8)$$

Where

$$B_2 = \frac{\mu_1 - \mu_2}{\tan \alpha - \tan \beta}$$

A_1 is incoming area at tube and A_2 is exit area at tube

Case IV : Frictionless wire drawing

Case (iii): Now put $\mu = 0$ in initial equation (2)

So,
$$\frac{d\sigma_x}{dr} + \frac{2\sigma_x}{r} + \frac{2P_x}{r} = 0$$

$$\sigma_x + P_x = \sigma_0 \quad \left[\because K' = \frac{\sigma_0}{2} \right]$$

$$\int d\sigma_x = \int -\frac{2\sigma_0}{r} dr$$

$$\sigma_x = -2\sigma_0 \ln(r) + C_1$$

No back pull

Boundary conditions

$$r = R_i; \sigma_x = 0$$

$$\sigma_d = \sigma_0 \ln \left(\frac{R_i}{R_f} \right)^2$$

$$\sigma_d = \sigma_0 \ln \left(\frac{\pi R_i}{\pi R_f} \right)^2$$

$$\sigma_d = \sigma_0 \ln \left(\frac{A_i}{A_f} \right) \Rightarrow \sigma_d = \sigma_0 \ln R \quad \dots(9)$$

Drawing force in all the cases = $\sigma_d \times \pi R_0^2$

When $\sigma_d = \sigma_0$ then maximum reduction occurs

So,

$$1 = \ln \left(\frac{A_i}{A_f} \right)$$

$$e = \frac{A_i}{A_f}$$

$$\% \text{ reduction} = \frac{A_i - A_f}{A_i} \times 100$$

$$= \left(1 - \frac{A_f}{A_i} \right) \times 100$$

$$= \left(1 - \frac{1}{e} \right) \times 100$$

$$\% \text{ reduction} = \left(\frac{e-1}{e} \right) \times 100 = 63\%$$

For extrusion:

the boundary conditions will be reverse i.e.

$$r = R_f; \sigma_x = \sigma_b = 0$$

$$\sigma_d = 2K' \left[\frac{1+B}{B} \right] \left[1 - \left(\frac{A_f}{A_i} \right)^B \right]$$

When

$$r = R_0; \sigma_x = 0$$

$$\sigma_d = 2K' \left[\frac{1+B}{B} \right] \left[\left(\frac{A_i}{A_f} \right)^B - 1 \right]$$

$$\sigma_d = 2K' \left[\frac{1+B}{B} \right] [R^B - 1] = \sigma_0 \left(\frac{1+B}{B} \right) (R^B - 1) \quad \dots(10)$$

where R is extrusion ratio.

Example : 5.2

In a drawing operation the initial diameter of the blank is given as 100mm and final diameter of the blank is 50mm. Find the load required for the operation. Given $\sigma_0 = 250 \text{ MPa}$.

Solution :

$$D_i = 100 \text{ mm}$$

$$D_f = 50 \text{ mm}$$

$$\sigma_0 = 250 \text{ MPa}$$

$$\sigma_d = \sigma_0 \ln R = 346.51 \text{ MPa}$$

$$\text{Load} = \frac{\pi}{4} D_f^2 \sigma_d = \frac{\pi}{4} (50^2) 346.51 = 680.37 \text{ kN}$$

Example : 5.3

An Aluminium rod of 6.25 mm diameter is drawn into wire of 5.6 mm diameter. Semi die angle is 10.1° . Find the drawing stress, considering the friction to be 0.04 and nominal stress 35 MPa. Also calculate the maximum reduction that can be given to material.

Solution :

$$d_i = 6.25 \text{ mm}$$

$$d_o = 5.6 \text{ mm}$$

$$\alpha = 10.1^\circ$$

$$\mu = 0.04$$

$$\sigma_0 = 35 \text{ MPa}$$

$$\sigma_d = ?$$

σ_b is not given so it is zero

$$\sigma_d = \sigma_0 \left(\frac{B+1}{B} \right) \left[1 - \left(\frac{r_f}{r_i} \right)^{2B} \right]$$

$$B = \mu \cot \alpha$$

$$B = 0.04 \cot (10.1)$$

$$B = 0.224$$

$$\sigma_d = 35 \left(\frac{0.224+1}{0.224} \right) \left[1 - \left(\frac{5.6}{6.25} \right)^{2(0.224)} \right]$$

$$\sigma_d = 9.17 \text{ MPa}$$

Maximum reduction

$$\sigma_d = \sigma_0 \text{ (For maximum reduction)}$$

$$1 = \left(\frac{B+1}{B} \right) \left[1 - \left(\frac{A_f}{A_i} \right)^B \right]$$

$$1 = \left(\frac{0.224+1}{0.224} \right) \left[1 - \left(\frac{A_f}{A_i} \right)^{0.224} \right]$$

$$\left(\frac{A_f}{A_i} \right) = 0.403$$

$$\% \text{ reduction} = \left(\frac{A_i - A_f}{A_i} \right) \times 100 = (1 - 0.403) \times 100$$

$$\therefore \% \text{ reduction} = 59.6\%$$

Example : 5.4

An alloy is extruded in forward extrusion process from 150 mm diameter billet to 50mm diameter rod, the mean flow stress of material is 250 MPa. The billet is 380 mm long. Semi die angle is 60° and coefficient of friction is 0.1. Determine extrusion load.

Solution :

$$D_i = 150 \text{ mm}; D_f = 50 \text{ mm}$$

$$\sigma_m = \sigma_0 = 250 \text{ MPa}; \alpha = 60^\circ$$

$$L = 380 \text{ mm}; \mu = 0.1$$

$$B = \mu \cot \alpha$$

$$= 0.1 \cot 60^\circ = 0.0577$$

For plane strain

$$K' = \frac{\sigma_0}{\sqrt{3}}$$

$$K' = \frac{250}{\sqrt{3}} = 144.33 \text{ MPa}$$

$$\sigma_d = \sigma_0 \left(\frac{1+B}{B} \right) (R^B - 1)$$

$$\sigma_d = 250 \left(\frac{1+0.0577}{0.0577} \right) (9^{0.0577} - 1)$$

$$\sigma_d = 619.4 \text{ MPa}$$

$$P_f = \frac{4K'L}{D} = \frac{4(144.33)(380)}{150}$$

$$P_f = 1462 \text{ MPa}$$

$$P = \sigma_d + P_f$$

$$P = 2081.94 \text{ MPa}$$

$$\begin{aligned} \text{Total load} &= 2081.94 \times \frac{\pi}{4} \times 150^2 \times 10^{-6} \\ &= 36.79 \text{ MN} \end{aligned}$$

Example : 5.5

Determine the drawing stress to reduce the 10 mm diameter of steel to 8 mm with a semi die angle of 6° and coefficient of friction of 0.09. Consider the flow curve equation of material to be $\sigma_f = 1300\epsilon^{0.3}$ MPa.

Solution :

Given data

$$\alpha = 6^\circ$$

$$\mu = 0.09$$

$$B = \mu \cot \alpha = 0.09 \cot 6$$

$$= 0.857$$

True strain

$$(\epsilon) = \ln\left(\frac{l_f}{l_i}\right) = \ln\left(\frac{A_i}{A_f}\right)$$

$$\epsilon = \ln\left(\frac{d_i^2}{d_f^2}\right) = \ln\left(\frac{10}{8}\right)^2 = 0.446$$

Mean flow stress

$$\begin{aligned} \sigma_0 &= \sigma_{fm} = \frac{K\epsilon^n}{n+1} \\ &= \frac{1300(\epsilon)^{0.3}}{1.3} = 785 \text{ MPa} \end{aligned}$$

So the drawing stress

$$\begin{aligned} \sigma_d &= \sigma_0 \left(\frac{1+B}{B} \right) \left[1 - \left(\frac{r_f}{r_i} \right)^{2B} \right] \\ \sigma_d &= 785 \left(\frac{1+0.857}{0.857} \right) \left[1 - \left(\frac{4}{5} \right)^{2 \times 0.857} \right] \\ \sigma_d &= 540.5 \text{ MPa} \end{aligned}$$

Example : 5.6

After passing through the conical portion, the wire passes through the die land of 2 mm length. The incoming wire diameter is 6 mm and outgoing diameter is 5 mm. The semi die angle is 8° and coefficient of friction is 0.05. If the nominal strength of material is 25 MPa, calculate the pull required to draw the wire.

Solution :

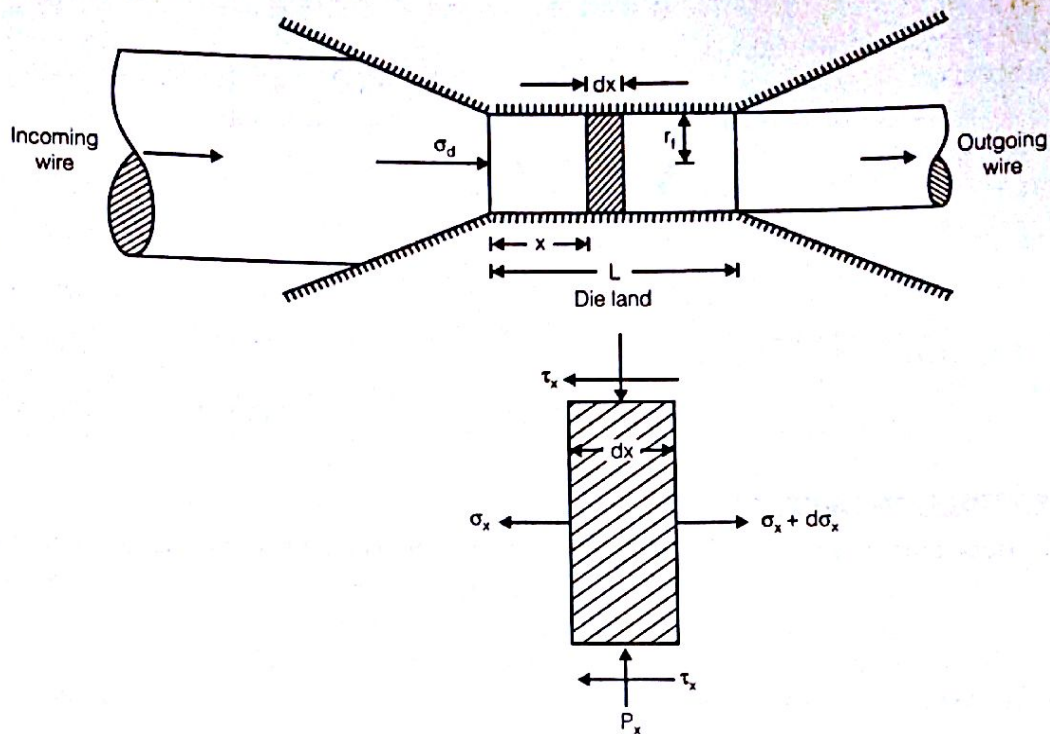


Fig. 5.10

Having the equilibrium of forces in the horizontal direction

$$(\sigma_x + d\sigma_x) \pi r_f^2 - \sigma_x \pi r_f^2 - \tau_x \cdot 2\pi r_f dx = 0 \quad \dots(11)$$

So
$$d\sigma_x = \frac{2\tau_x}{r_f} dx = \frac{2\mu p_x}{r_f} dx$$

Considering σ_x and p_x and also due to spherical coordinate system both von-mises and Tresca will lead to the same result.

$$\begin{aligned}\sigma_x + P_x &= \sigma_0 \\ P_x &= \sigma_0 - \sigma_x\end{aligned}$$

$$\int \frac{d\sigma_x}{\sigma_0 - \sigma_x} = \int \frac{2\mu}{r_f} dx$$

$$\ln(\sigma_0 - \sigma_x) = \frac{-2\mu}{r_f} x + c_1 \quad \dots(12)$$

Boundary condition : at $x = 0, \sigma_x = \sigma_d$ where

$$\sigma_d = \sigma_0 \left(\frac{1+B}{B} \right) \left[1 - \left(\frac{r_f}{r_i} \right)^{2B} \right]$$

So
$$\sigma_x = \sigma_0 - (\sigma_0 - \sigma_d) e^{-\frac{2\mu x}{\eta}} \quad \dots(13)$$

at $x = L, d_y = s_y$

Data given in the problem $\alpha = 8^\circ, \mu = 0.05, \sigma_0 = 25 \text{ MPa}$

So,

$$r_i = 3 \text{ mm}, r_f = 2.5 \text{ mm}, L = 2 \text{ mm}$$

$$B = \mu \cot \alpha = 0.355$$

$$\sigma_d = 25 \left(\frac{1+0.355}{0.355} \right) \left(1 - \left(\frac{2.5}{3} \right)^{2 \times 0.355} \right)$$

$$\sigma_d = 11.72 \text{ MPa}$$

$$\sigma_x = 25 - (25 - 11.72) e^{-\frac{2 \times 0.05 \times 2}{2.5}}$$

$$\sigma_t = 12.74 \text{ MPa}$$

So Pull required to draw the wire is:

$$= 12.74 \times 10^6 \times \frac{\pi}{4} (0.005)^2 = 250.16 \text{ N}$$

5.5 EXTRUSION DEFECTS

Surface cracking : If extrusion temperature, friction or speed is too high, surface temperature raise significantly and this condition may cause surface cracking and tearing. Surface cracking may also occur at lower temperatures because of periodic sticking of the extruded product along the die land. Because of this extrusion pressure increases and causes cracking.

Pipe defect : The unusual type of the metal flow pattern tends to draw surface impurities toward the center of the billet, this defect is called pipe defect, also called tail pipe or fishtailing. This can be minimized by modifying the flow pattern to more uniform. These impurities can also be removed by chemical etching of the surface oxides before extrusion.

Internal cracking : Extruded product center can develop various cracks called center cracking, center burst, arrowhead fracture or chevron cracking. These cracks are attributed to a state of hydrostatic tensile stresses at the center line in the deformation zone in the die. Center cracking increases with increase in die angle, increase in amount of impurities, and increase in extrusion ratio and friction.

5.6 FORGING

Forging is shaping of metals by squeezing them between two or more dies to obtain the desired shape. Forging can be done either at room temperature or at elevated temperature. If the forging operation is carried out below the recrystallization temperature, it's known as cold forging and if at temperature above recrystallization is called hot forging. At elevated temperatures there will not be any work hardening.

If forging is done in an open hearth is known as smith forging. In this, hot work piece given desired shape by using hand held tools and hammers. Now-a-days power driven hammers are used to impart the repeated blows. The anvil and hammer are mostly flat and the desired shape is obtained by a manipulation of the job between the blows.

Edging : It is performed by a pair of concave dies and the material moves toward the center and it increases the size of stock.

Fullering : It is performed by a pair of convex dies and in this material moves away from the center, this decreases the size of a slab.

There are three types of forging

1. Open die forging

2. Closed die forging

3. Impression die forging.

Open die forging : In open die forging material is kept in the lower die and hammer comes in contact with the material. This results in poor surface finish and also cracks appear at top surface over the forged component. So a layer of material has to be removed from work piece. So in open die forging there is poor material utilization. In this there is less control in determining mechanical properties and difficult to maintain tolerances and surface finish.

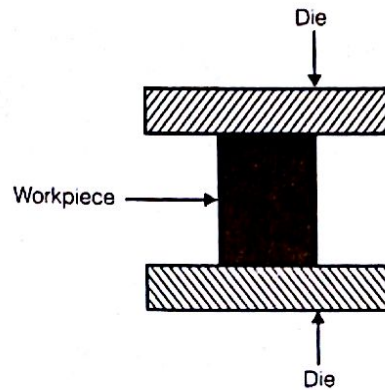


Fig 5.11 : (a) Open die forging

Forgings are made by this process when:

1. The forging is too large to be produced in closed dies
2. The required mechanical properties of the worked metal that can be developed by open-die forging cannot be obtained by other deformation processes
3. The quantity required is too small to justify the cost of closed dies

Closed die forging : In closed die forging operation metal is kept between top and bottom dies. Bottom die is connected with a gutter and the extra material settles down in those gutters called flash. After forging these flash has to be removed. This is the method by which we can make coins. Closed-die forging is the shaping of hot metal completely within the walls or cavities of two dies that come together to enclose the workpiece on all sides. The impression for the forging can be entirely in either die or can be divided between the top and bottom dies. The forging stock, generally round or square bar, is cut to length to provide the volume of metal needed to fill the die cavities, in addition to an allowance for flash and sometimes for a projection for holding the forging. The flash allowance is, in effect, a relief valve for the extreme pressure produced in closed dies. Flash also acts as a brake to slow the outward flow of metal in order to permit complete filling of the desired configuration.

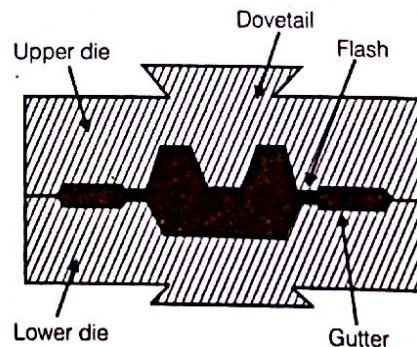


Fig 5.11 : (b) Closed die forging

Impression die forging : In impression die forging the calculated amount of material is kept in the pair of dies and there are no gutters with the lower die and it acquires the shape of the die cavities while being forced between two shaped dies. The thin flash which flows outwards cools rapidly and because of its frictional resistance it subjects the material in the die cavity to high pressures there by encouraging the filling of the die cavity. It provides very good surface finish.

Some other processes are :

Hubbing : Impressions are there in the hammer and by repeated blow to work piece same impressions are developed in the work piece.

Upset forging : It is a process of forging a portion of work. The upsetting operation may be closed or open. The operation involves a longitudinal compression of the bar stock. If the overhanging portion is greater than '3d' close die upsetting is performed otherwise material will bend and it will appear defect like fold. In an open die upsetting the length of the unsupported portion should not exceed 3d to prevent buckling. The process is used to produce bolt head.

Swaging : Material is kept between dies and the forging load is applied to the work through these dies. Metal moves in the longitudinal direction. The rifle barrels are being produced by this process.

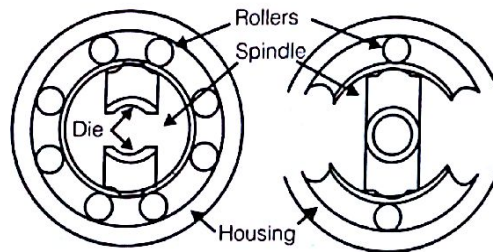


Fig 5.11 : (c) Rotary swaging

Roll forging : Rolls are made up of non uniform radius and when the lump in radius comes in contact with the material, work piece material deforms. Railway wheels are made by this procedure. The process is also used for reducing the diameter of rods. The heated work piece is placed between the dies in an open position and after a half revolution of the rolls the work pieces rolled out it is then put in the smaller group and the operation continued until the desired dimension is achieved. Roll forging (also known as hot forge rolling) is a process for reducing the cross-sectional area of heated bars or billets by passing them between two driven rolls that rotate in opposite directions and have one or more matching grooves in each roll. The principle involved in reducing the cross-sectional area of the work metal in roll forging is essentially the same as that employed in rolling mills to reduce billets to bars.

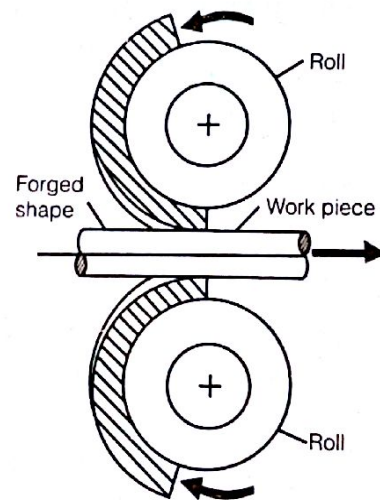


Fig 5.11 : (d) Principle of roll forging

5.6.1 Forging defects

- **Cracks:** Internal as well as external cracks appear due to excessive cold working.
- **Fold:** It is discontinuity produced when two surfaces of metal fold against each other without fusing properly.

- **Barrelling** : when hot work comes in contact with the dies there will be a decrease in the temperature of the surface coming in contact with dies. Upon applying the forging load, since central portion will have lower flow stresses, it will move faster than the material near the edges. This result in non cylindrical large components called Barrelling.

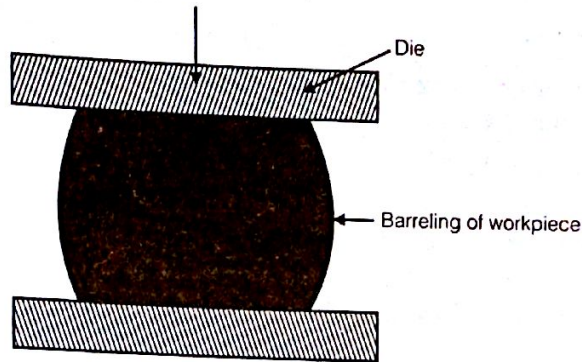


Fig. 5.12

5.6.2 Analysis of forging

(a) Forging between Flat dies : (plane strain compression)

After forging the width of the stock does not change. Height decreases and length increases. Let say h is the final height of billet and w is the width.

Let us have equilibrium of forces in horizontal direction.

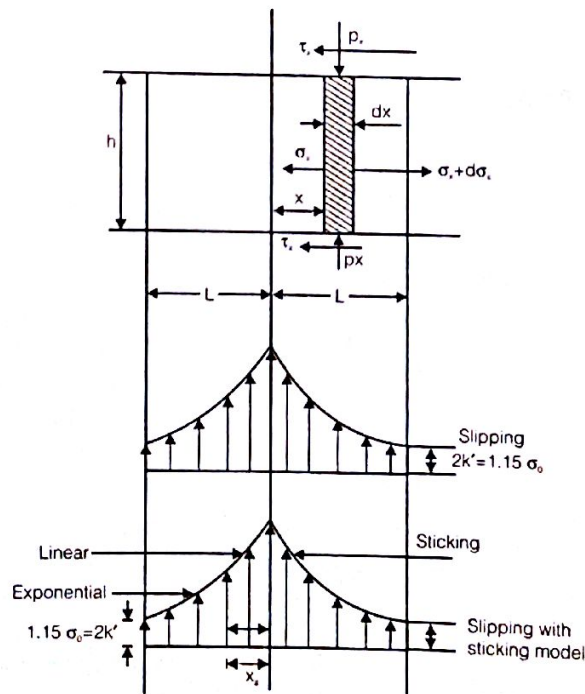


Fig. 5.13 : Friction hill (forging in rectangular dies)

$$\begin{aligned}
 (\sigma_x + d\sigma_x)hw - \sigma_x hw - 2\tau_x dx &= 0 \\
 \sigma_x hw + d\sigma_x hw - \sigma_x hw - 2\tau_x dx &= 0 \\
 d\sigma_x hw - 2\tau_x dx &= 0
 \end{aligned}
 \quad \dots(14)$$

$$d\sigma_x = \frac{2\tau_x dx}{h} \quad \dots(15)$$

as

$$\tau_x = \mu p_x$$

Assuming σ_x and p_x are principle stresses and also assuming that the material is behaving as a plane stress case. So $2K = \sigma_0$

$$\sigma_x + p_x = 2K'$$

$$\frac{d\sigma_x}{dx} + \frac{dp_x}{dx} = 0$$

$$\frac{d\sigma_x}{dx} = -\frac{dp_x}{dx}$$

From equation (1)

$$-dp_x = \frac{2\tau_x dx}{h}$$

$$-dp_x = \frac{2\mu p_x}{h} dx$$

$$\int \frac{-dp_x}{p_x} = \int \frac{2\mu}{h} dx$$

$$\ln p_x = \frac{-2\mu x}{h} + c_1$$

Boundary conditions; at $x = L$, $\sigma_x = 0$

So $P_x = 2K'$

$$\ln (2K') = \frac{-2\mu L}{h} + c_1$$

So

$$\ln P_x - \ln (2K') = \frac{-2\mu x}{h} + \frac{2\mu L}{h}$$

$$\ln \left(\frac{P_{x1}}{2K'} \right) = \frac{2\mu (L-x)}{h}$$

$$\frac{P_{x1}}{2K'} = e^{\frac{2\mu (L-x)}{h}}$$

$$P_{x1} = 2K' e^{\frac{2\mu (L-x)}{h}}$$

$$P_{x1} = 1.15\sigma_0 e^{\frac{2\mu (L-x)}{h}} \quad (\text{forging pressure without sticking}) \quad \dots(16)$$

$$(K' = \frac{\sigma'}{\sqrt{3}}, \text{ since it is plane strain condition})$$

When the shear stress becomes equal to the yield shear strength, sticking takes place between the die and the work piece material.

Forging load

Because force is symmetric on two sides so

$$F = 2 \int_0^L p_x w dx$$

$$\text{Average die pressure} = \frac{F}{2Lw}$$

For sticking

$$\tau_x = K' [\text{yield strength}]$$

$$\text{at } x = x_s \quad \mu p_x = K' = \tau_x$$

Apply this condition in previous equation

$$\int dp_x = - \int \frac{2K'}{h} dx$$

$$P_{x_2} = - \frac{2K'x}{h} + C_2 \quad \dots(17)$$

$$\text{Boundary conditions at; } x = x_s; p = \frac{K'}{\mu}$$

$$\frac{K'}{\mu} = - \frac{2K'x_s}{h} + C_2 \quad \dots(18)$$

(17) and (18)

$$P_{x_2} = \frac{K'}{\mu} + \frac{2K'}{h} (x_s - x) \quad \text{Forging pressure with sticking} \quad \dots(19)$$

Calculation of sticking let

$$\Rightarrow \quad = 2K' e^{\frac{2\mu}{h}(L-x_s)}$$

$$\Rightarrow \quad \frac{1}{2\mu} = e^{\frac{2\mu}{h}(L-x_s)}$$

$$\Rightarrow \quad \frac{2\mu}{h}(L-x_s) = \ln\left(\frac{1}{2\mu}\right)$$

$$\Rightarrow \quad x_s = L - \frac{h}{2\mu} \ln\left(\frac{1}{2\mu}\right) \quad \dots(20)$$

Forging load with sticking and slipping

$$\text{Load} = 2 \left[\int_0^{x_s} P_{x_2} w dx + \int_{x_s}^L P_{x_1} w dx \right] \quad \dots(21)$$

This is the load with sticking

(B) Forging between circular dies

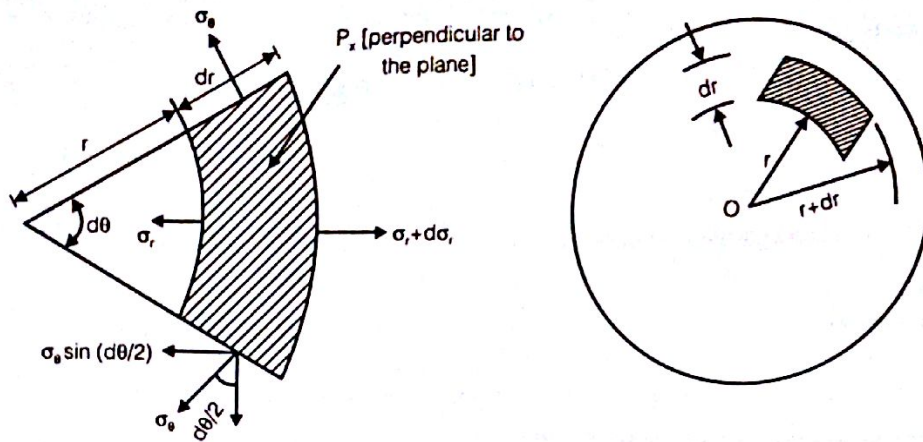


Fig. : 5.14

Considering the equilibrium of forces.

$$(\sigma_r + d\sigma_r)(r + dr) d\theta h - \sigma_r r d\theta h - 2\sigma_\theta \sin \frac{d\theta}{2} dr h - 2\tau_r (rd\theta dr) = 0 \quad \dots(22)$$

Neglect higher order terms and divide by $dr h r$

$$(\sigma_r + \sigma_r dr + d\sigma_r r + d\sigma_r dr) d\theta h - \sigma_r r d\theta h - 2\sigma_\theta \sin \frac{d\theta}{2} dr h - 2\tau_r r d\theta dr = 0$$

$$\sin \frac{d\theta}{2} \approx \frac{d\theta}{2}$$

$$\frac{\sigma_r}{r} + \frac{d\sigma_r}{dr} - \frac{\sigma_\theta}{r} - \frac{2\tau_r}{h} = 0$$

$$\frac{d\sigma_r}{dr} + \left[\frac{\sigma_r - \sigma_\theta}{r} \right] - \frac{2\tau_r}{h} = 0 \quad \dots(23)$$

Circumferential strain

$$\epsilon_\theta = \frac{(r + dr) d\theta - r d\theta}{r d\theta} = \frac{dr d\theta}{r d\theta}$$

$$\epsilon_\theta = \frac{dr}{r}$$

This is also known as radial strain

$$\epsilon_\theta = \epsilon_r$$

If these are equal then $\sigma_\theta = \sigma_r$

- (a) Since $\sigma_r = \sigma_\theta = \sigma$, normal pressure (forging) and friction stress in τ_r (τ_{RX}) and other friction stresses like $\tau_{\theta y}$ and $\tau_{R\theta}$ are zero. So von-mises yield criteria

$$\frac{1}{6} \left\{ (\sigma_r - \sigma_\theta)^2 + (\sigma_\theta - \sigma_{yy})^2 + (\sigma_{yy} - \sigma_r)^2 \right\} + \tau_{Ry}^2 + \tau_{y\theta}^2 = \frac{\sigma_0^2}{3}$$

Putting all the values in the above expression we get

$$(\sigma_r + p_x)^2 + 3\tau_x^2 = \sigma_0^2$$

(b) If σ_r and p_x are the principal stresses then friction can be neglected to zero.

So

$$\sigma_r + p_x = \sigma_0$$

In case of pure torsion if K' is the yield strength in shear then

$$3K'^2 = \sigma_0^2$$

So

$$K' = \frac{\sigma_0}{\sqrt{3}}$$

So

$$\sigma_r + p_x = \sqrt{3}K'$$

The following analysis is adapted from B. Avitzler, "Metal forming: process and analysis". TMH, 1977.

So the corresponding formulas for circular compression are

$$p_{r1} = \sigma_0 e^{\frac{2\mu}{h}(R-r)} \quad \dots(24)$$

$$p_{r2} = \frac{K'}{\mu} + \frac{2K'}{h}(R_s - r) \quad \dots(25)$$

and sticking radius is

$$R_s = R - \frac{h}{2\mu} \ln \left(\frac{1}{\sqrt{3}\mu} \right) \quad \dots(26)$$

Forging load:

$$\text{Without sticking} = \int_0^R p_{r1} 2\pi r dr \quad \dots(27)$$

$$\text{With sticking} = \int_0^{R_s} p_{r2} 2\pi r dr + \int_{R_s}^R p_{r1} 2\pi r dr \quad \dots(28)$$

Example : 5.7

In a forging operation the initial and final diameter of blank is 200 mm and 400 mm. Height is 60 mm. find true strain?

Solution :

Given data is

$$d_1 = 200 \text{ mm}$$

$$d_2 = 400 \text{ mm}$$

$$h_1 = 60 \text{ mm}$$

$$\frac{\pi}{4} d_1^2 h_1 = \frac{\pi}{4} d_2^2 h_2$$

$$d_1^2 h_1 = d_2^2 h_2$$

$$h_2 = 15 \text{ mm}$$

$$\epsilon = \ln \frac{h_1}{h_2} = \ln \frac{60}{15} = 1.38$$

Example : 5.8

A strip of lead with initial dimensions 24 mm × 24 mm × 150 mm is forged between two flat dies to a final size of 6 mm × 96 mm × 150 mm. If the coefficient of friction is 0.05, determine the maximum forging force. The average yield stress of lead in tension is 7 N/mm².

Solution :

Given,

Initial dimensions of billet 24 × 24 × 150 mm³

Final dimensions of billet 6 × 96 × 150 mm³

as width never changes after forging of rectangular billet and all the calculations of forging operation are done on the final dimensions of the billet.

So the dimensions of billet are as

thickness of billet (h) = 6 mm

length of billet (2L) = 96 mm

width of billet (w) = 150 mm

coefficient of friction (μ) = 0.05

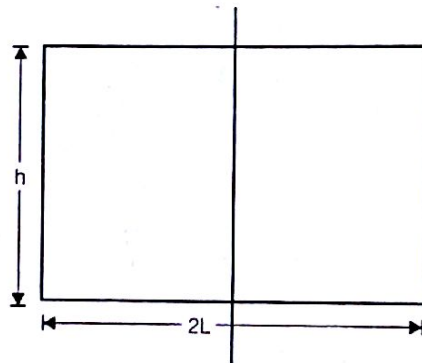


Fig. : 5.15

Step I : Checking for the sticking

As we know sticking length in case of rectangular billet is given by

$$\text{sticking length } (x_s) = L - \frac{h}{2\mu} \ln \left(\frac{1}{2\mu} \right)$$

$$x_s = 48 - \frac{6}{2 \times 0.05} \ln \left(\frac{1}{2 \times 0.05} \right)$$

$$x_s = -90.155 \text{ mm}$$

negative sign shows that sticking will not occur during the operation.

Step II :

As we know that forging stress when there is no sticking is given by

$$P_{x_1} = 2K' e^{\frac{2\mu}{h}(L-x)}$$

as forging of rectangular billet is a case of plane strain,

So

$$2K' = \frac{2\sigma_0}{\sqrt{3}}$$

$$\sigma_0 = 7 \text{ N/mm}^2 \text{ (given)}$$

where σ_0 = average yield stress

⇒

$$P_{x_1} = \frac{2 \times 7}{\sqrt{3}} e^{\frac{2 \times 0.05}{6}(48-x)}$$

$$P_{x_1} = 8.08 e^{\frac{(48-x)}{60}}$$

so,

$$\text{forging load} = 2x \int_0^L P_{x_1} \cdot w \cdot dx$$

$$= 2x \int_0^{48} 8.08 e^{\frac{(48-x)}{60}} \times 150 \, dx$$

$$= (2 \times 8.08 \times 150) \int_0^{48} e^{\frac{(48-x)}{60}} \, dx$$

$$= (2 \times 8.08 \times 150) \times (-60) \left[e^{\frac{(48-x)}{60}} \right]_0^{48}$$

$$= -(2 \times 8.08 \times 150 \times 60) \left(e^0 - e^{\frac{48}{60}} \right)$$

$$\text{forging load} = 178.24 \, \text{kN}$$

Example : 5.9

A strip of lead with initial dimensions 24 mm × 24 mm × 150 mm is forged between two flat dies to a final size of 6 mm × 96 mm × 150 mm. If the coefficient of friction is 0.25, determine the maximum forging force. The average yield stress of lead in tension is 7 N/mm².

Solution :

Given,

Initial dimensions of billet 24 × 24 × 150 mm³

Final dimensions of billet 6 × 96 × 150 mm³

as width never changes after forging of rectangular billet and all the calculations of forging operation are done on the final dimensions of billet

So, the dimensions of billet are

thickness of billet (h) = 6 mm

length of billet (2L) = 96 mm

width of billet (w) = 150 mm

coefficient of friction (μ) = 0.25

Step I : Checking for the sticking

As we know sticking length in case of rectangular billet is given by

$$\text{Sticking length } (x_s) = L - \frac{h}{2\mu} \ln \left(\frac{1}{2\mu} \right)$$

$$x_s = 48 - \frac{6}{2 \times 0.25} \ln \left(\frac{1}{2 \times 0.25} \right)$$

$$x_s = 39.68 \, \text{mm}$$

+ve sign shows sticking will occur during the forging operation.

Step II :

As we know that forging stress during sticking zone is given by

$$P_{x_2} = \frac{K'}{\mu} + \frac{2K'}{h}(x_s - x)$$

as forging of rectangular billet is a case of plane strain,

$$\text{So } 2K' = \frac{2\sigma_0}{\sqrt{3}} \quad \text{where, } \sigma_0 = \text{mean flow stress}$$

$$\sigma_0 = 7 \text{ N/mm}^2 \text{ (given)}$$

$$\Rightarrow P_{x_2} = \frac{\sigma_0}{\sqrt{3}\mu} + \frac{2\sigma_0}{\sqrt{3}h}(x_s - x)$$

$$P_{x_2} = \left(\frac{7}{\sqrt{3} \times 25} \right) + \left(\frac{2 \times 7}{\sqrt{3} \times 6} \right) (39.68 - x)$$

$$P_{x_2} = 16.16 + 53.45 - 1.347x$$

$$P_{x_2} = 69.61 - 1.347x$$

$$\begin{aligned} \text{So, forging load during sticking} &= 2x \int_0^{x_s} P_{x_2} \cdot w dx \\ &= (2 \times 150) \times \int_0^{39.68} (69.61 - 1.347x) dx \\ &= 300x \left| 69.61x - \frac{1.347x^2}{2} \right|_0^{39.68} \\ &= 300x \left| (69.61 \times 39.68 - \frac{1.347}{2} (39.68)^2) \right| \\ &= 510.507 \text{ kN} \end{aligned}$$

Step III :

Forging stress during Non-sticking zone. As we know forging stress during non-sticking zone is given by

$$P_{x_1} = 2K' e^{\frac{2\mu}{h}(L-x)}$$

$$P_{x_1} = \left(\frac{2 \times \sigma_0}{\sqrt{3}} \right) \cdot e^{\frac{2 \times 25}{6}(48-x)}$$

$$P_{x_1} = 8.08 e^{\frac{(48-x)}{12}}$$

$$\text{So, Forging load} = 2x \int_{x_s}^L P_{x_1} \cdot w dx$$

$$= (2 \times w) \int_{39.68}^{48} 8.08 e^{\left(\frac{48-x}{12} \right)} dx$$

$$= (2 \times 150 \times 8.08) \times (-12) \left[e^{\frac{48-x}{12}} \right]_{39.68}^{48}$$

$$= -(2 \times 150 \times 8.08 \times 12) \left(e^0 - e^{\frac{48-39.68}{12}} \right)$$

So,

$$\begin{aligned} \text{total forging load} &= 29.098 \text{ kN} \\ &= \text{Load (1)} + \text{Load (2)} \\ &= 510.507 + 29.098 \\ \text{Total forging load} &= 539.60 \text{ kN} \end{aligned}$$

Example : 5.10

A certain disc of lead of radius 150 mm and thickness 50 mm is reduced to a thickness of 25 mm by open die forging. If the coefficient of friction between the job and die is 0.25, determine the maximum forging force. The average yield stress of lead can taken as 4 N/mm²

Solution :

Given

Circular billet and open die forging

Initial radius of circular billet (R_i) = 150 mm

Initial thickness of circular billet (h_i) = 50 mm

Final radius of circular billet (R_f) = R_f mm

Final thickness of circular billet (h_f) = 25 mm

Coefficient of friction (μ) = 0.25

average shear yield stress = $\sigma_0 = 4 \text{ N/mm}^2$

Calculation of final radius of circular billet after forging operation

As, (volume of billet before forging) = (volume of billet after forging)

$$\pi R_i^2 \times h_i = \pi R_f^2 \times h_f$$

$$\Rightarrow R_f^2 = R_i^2 \times \frac{h_i}{h_f}$$

$$\Rightarrow R_f^2 = 150^2 \times \frac{50}{25}$$

$$\Rightarrow R_f = 212.13 \text{ mm}$$

As we know all the forging calculations are done on the final dimensions of the billet after forging operation.

So, final dimensions of billet are

$$\text{Radius of billet (R)} = R_f = 212.13 \text{ mm}$$

$$\text{thickness of billet (h)} = h_f = 25 \text{ mm}$$

Step I :

$$\begin{aligned} \text{Sticking radius (R}_s\text{)} &= R - \frac{h}{2\mu} \left[\ln \left(\frac{1}{\sqrt{3}\mu} \right) \right] \\ &= (212.3) - \left(\frac{25}{2 \times 0.25} \right) \left[\ln \left(\frac{1}{\sqrt{3} \times 0.25} \right) \right] \\ R_s &= 170.28 \text{ mm} \end{aligned}$$

+ ve sign shows that sticking will occur.

Step II:

Calculation for the stress in the sticking zone; as we know stress in the sticking zone is given by

$$P_{r2} = \frac{K'}{\mu} + \frac{2K'}{h} (R_s - r)$$

$$K' = \frac{\sigma_0}{2}$$

$$P_{r2} = \frac{1}{2} \left[\frac{4}{0.25} + \frac{2 \times 4}{25} (R_s - r) \right]$$

$$P_{r2} = 35.245 - 0.16 r$$

$$\begin{aligned} \text{So, forging load during sticking} &= \int_0^{R_s} P_{r2} 2\pi r dr \\ &= \int_0^{170.28} (35.245 - 0.16 r) 2\pi r dr \\ &= 2\pi \int_0^{170.28} (35.245 r - 0.16 r^2) dr \\ &= 1.556 \text{ MN} \end{aligned}$$

Forging load during sticking = 1.804 MN

Step III:

Calculation for the stress in non-sticking zone ($R_s - r$)

$$P_{r1} = \sigma_0 e^{\frac{2\mu}{h} (R - r)}$$

$$\Rightarrow = 4 \times e^{\frac{2 \times 0.25}{25} (212.13 - r)}$$

$$P_{r1} = 4 \times e^{\frac{(212.13 - r)}{50}}$$

So, forging load in = $\int_{R_s}^R P_{r1} 2\pi r dr$

$$\begin{aligned} \text{non-sticking region} &= \int_{170.28}^{212.13} (4 \times 2\pi) e^{\frac{(212.13 - r)}{50}} r dr \\ &= (8\pi) \int_{170.28}^{212.13} r e^{\left(\frac{212.13 - r}{50}\right)} dr \\ &= (8\pi) \left[-50 r e^{\left(\frac{212.13 - r}{50}\right)} - \int (-50) e^{\left(\frac{212.13 - r}{50}\right)} dr \right]_{170.28}^{212.13} \end{aligned}$$

$$\begin{aligned}
 &= (8\pi) \left[-50r \cdot e^{\left(\frac{212.13-r}{50}\right)} - (-50)^2 e^{\left(\frac{212.13-r}{50}\right)} \right]_{170.28}^{212.13} \\
 &= (8\pi) \left[\left(-50 \times 212.13 e^0 \right) - \left(-50 \times 170.28 e^{\frac{212.13-170.28}{50}} \right) - 50^2 \left(e^0 - e^{\frac{212.13-170.28}{50}} \right) \right] \\
 &= 0.309 \text{ MN}
 \end{aligned}$$

So, total forging load = Load (1) + Load (2)
 $= 1.556 + 0.309 = 1.865 \text{ MN}$

Example : 5.11

A cylinder of height 60 mm and diameter 100 mm is forged at room temperature between two flat dies. Find the die load at the end of compression to a height of 30 mm, using slab method of analysis. The yield strength of the work material is given as 120 N/mm² and the coefficient of friction is 0.05. Assume that volume is constant after deformation. There is no sticking. Also find the mean die pressure.

Solution :

Given

Initial height of cylinder (h_i) = 60 mm

Initial diameter of cylinder (D_i) = 100 mm

Final height of cylinder after forging (h_f) = 30 mm

Final diameter of cylinder after forging (D_f) = D_f mm

Coefficient of friction (μ) = 0.05

Yield strength = 120 N/mm²

Sticking is not present (given)

Step I : Calculation of final diameter of cylinder after forging

as (volume of cylinder before forging) = (volume of cylinder after forging)

$$\frac{\pi}{4} D_i^2 \times h_i = \frac{\pi}{4} D_f^2 \times h_f$$

$$\Rightarrow D_f^2 = D_i^2 \times \frac{h_i}{h_f} = 100^2 \times \frac{60}{30}$$

$$D_f = 141.42 \text{ mm}$$

$$\text{Radius } (R_f) = 70.71 \text{ mm}$$

As we know all the forging calculations are done on the final dimensions of the billet.

Step II : Calculation of forging stress

(No sticking) forging stress if sticking is not present is given by

$$P_{f1} = (2K') e^{\frac{2\mu}{h}(R-r)}$$

As we know forging of circular billet is a plane stress case

So, $2K' = \sigma_0$

where σ_0 = mean flow stress

$\sigma_0 = 120 \text{ N/mm}^2$ (given)

$$P_r = (120)e^{\left(\frac{70.71-r}{30}\right)}$$

So, forging load is given by $= \int_0^R P_r \times 2\pi r dr$

$$= (2\pi) \times (120) \int_0^{70.71} r \cdot e^{\left(\frac{70.71-r}{30}\right)} dr$$

$$= (240\pi) \left[(-300)r e^{\frac{(70.71-r)}{300}} - \int (-300)e^{\frac{(70.71-r)}{300}} dr \right]$$

$$= (240\pi) \left[-300r e^{\frac{(70.71-r)}{300}} - (300)^2 e^{\frac{70.71-r}{300}} \right]_0^{70.71}$$

$$= (240\pi) \left[(-300 \times 70.71 - 300^2) - \left(0 - 300^2 e^{\frac{70.71}{300}} \right) \right]$$

$$\text{Forging load} = 2.04 \text{ MN} \checkmark$$

$$\text{Mean die pressure} = \frac{\text{Load}}{\text{Total area}}$$

$$= \frac{2.04 \times 10^6}{\pi R^2} = \frac{2.04 \times 10^6}{\pi \times (70.71)^2}$$

$$\text{Mean Die Pressure} = 130 \text{ MPa}$$

Example : 5.12

A cylindrical specimen made up of steel is 150 mm in diameter and 100 mm high. It is upsetted by open die forging to a height of 50 mm. Assume that coefficient of friction is 0.2. Calculate the force required to forge the material. If flow curve equation is $\sigma_f = 1030 \epsilon^{0.17}$

Solution :

Given

Initial diameter of billet (D_i) = 150 mm

Initial height of billet (h_i) = 100 mm

Final height of billet (h_f) = 50 mm

Final diameter of billet (D_f) = D_f mm

Coefficient of friction (μ) = 0.2

Flow curve equation = $\sigma_f = 1030 \epsilon^{0.17}$

Step I : Calculation of final diameter of billet

(Volume of billet before forging) = (Volume of billet after forging)

$$\frac{\pi}{4} \times D_i^2 \times h_i = \frac{\pi}{4} \times D_f^2 \times h_f$$

$$D_f^2 = 150^2 \times \frac{100}{50}$$

$\Rightarrow$

$$D_f = 212.13 \text{ mm}$$

$$\text{Final radius of billet } (R_f) = \frac{D_f}{2} = 106 \text{ mm}$$

As we know all the forging calculations are done on the final dimensions of the billet.
So, final dimensions of billet are

$$\text{Radius of billet (R)} = R_f = 106 \text{ mm}$$

$$\text{Height of billet (h)} = h_f = 50 \text{ mm}$$

Step I : Checking for sticking

as we know sticking radius in case of forging of circular billet is given by

$$\begin{aligned} \text{Sticking Radius (R}_s) &= R - \frac{h}{2\mu} \ln \left(\frac{1}{\sqrt{3}\mu} \right) \\ &= 106 - \frac{50}{2 \times 0.2} \ln \left(\frac{1}{\sqrt{3} \times 0.2} \right) = -26.51 \text{ mm} \end{aligned}$$

-ve sign indicates that there will not be any sticking

Step II : Calculation of forging stress (No sticking)

As we know that stress in non-sticking zone is given by

$$P_{r_1} = 2K' e^{\frac{2\mu}{h}(R-r)}$$

as forging of circular billet is plane stress case

$$\text{So } 2K' = \sigma_0$$

$$\Rightarrow P_{r_1} = \sigma_0 e^{\frac{2\mu}{h}(R-r)}$$

as true strain (ϵ) is given by

$$\epsilon = \ln \left(\frac{h_i}{h_f} \right) = \ln \left(\frac{100}{50} \right) = 0.693$$

in case of circular billet;

$$\begin{aligned} \sigma_0 &= \sigma_f = 1030 \epsilon^{0.17} \\ &= 1030 \times (0.693)^{0.17} \\ \sigma_0 &= \sigma_f = 967.74 \text{ MPa (due to compression)} \end{aligned}$$

$$\Rightarrow P_{r_1} = 967.74 e^{\frac{2 \times 0.2}{50}(106-r)}$$

$$P_{r_1} = 967.74 e^{\left(\frac{106-r}{125} \right)}$$

$$\text{So, } \text{forging load} = \int_0^R P_{r_1} \times 2\pi r \, dr$$

$$= (967.74 \times 2\pi) \int_0^{106} r e^{\frac{(106-r)}{125}} \, dr$$

$$= (6080.48) \left[-125r e^{\frac{(106-r)}{125}} - \int (-125) e^{\frac{(106-r)}{125}} \, dr \right]_0^{106}$$

$$= (6080.48) \left[-125r e^{\frac{(106-r)}{125}} - (-125)^2 e^{\frac{(106-r)}{125}} \right]_0^{106}$$

$$= (6080.48) \left[(-125 \times 106 - 125^2) - \left(0 - 125^2 e^{\frac{106}{125}} \right) \right] = 46.26 \text{ MN}$$

So, Forging load = 46.26 MN

Example : 5.13

A circular disc of 200 mm diameter and 70 mm height is forged to 40 mm height. If the flow curve equation of the material is given by $\sigma_f = 200 (0.01 + \epsilon)^{0.41}$ MPa and coefficient of friction is 0.05. Determine forging load, mean die pressure and maximum pressure.

Solution :

Initial diameter of billet (D_i) = 200 mm

Initial height of billet (h_i) = 70 mm

Final height of billet (h_f) = 40 mm

Final diameter of billet (D_f) = D_f mm

Coefficient of friction (μ) = 0.05

Flow curve equation is

$$\sigma_f = 200 (0.01 + \epsilon)^{0.41}$$

Step I : Calculation of final diameter of billet

as (volume of billet before forging) = (Volume of billet after forging)

$$\frac{\pi}{4} \times D_i^2 \times h_i = \frac{\pi}{4} \times D_f^2 \times h_f$$

$$D_f^2 = D_i^2 \times \frac{h_i}{h_f} = 200^2 \times \frac{70}{40} = 70,000$$

$$D_f = 264.57 \text{ mm}$$

$$\text{Radius } (R_f) = \frac{D_f}{2} = 132.28 \text{ mm}$$

Step II : Checking for sticking

As we know sticking radius in case of circular billet is given by,

$$\begin{aligned} \text{Sticking radius } (R_s) &= R - \frac{h}{2\mu} \ln \left(\frac{1}{\sqrt{3}\mu} \right) \\ &= 132.28 - \frac{40}{2 \times 0.05} \ln \left(\frac{1}{\sqrt{3} \times 0.05} \right) \end{aligned}$$

$$R_s = -846.29 \text{ mm}$$

-ve sign indicates that will not be any sticking

Step III :

as true strain (ϵ) is given by

$$\epsilon = \ln \left(\frac{h_i}{h_f} \right) = \ln \left(\frac{70}{40} \right) = 0.559$$

So mean flow stress (σ_0) is

$$\sigma_0 = \sigma_f = 200 \times (0.01 + 0.559)^{0.41}$$

$$\sigma_0 = 158.71 \text{ MPa}$$

Step IV : Calculation of forging stress in case of no sticking

$$P_{r1} = 2K'e^{\frac{2\mu}{h}(R-r)}$$

as forging of circular billet is a case of plane stress.

So,

$$2K' = \sigma_0$$

$$P_{r1} = \sigma_0 e^{\frac{2\mu}{h}(R-r)}$$

$$= 158.71 e^{\frac{2 \times 0.05}{40} (132.28 - r)}$$

$$P_{r1} = 158.71 \times e^{\frac{(132.28 - r)}{400}}$$

So,

$$\text{forging load} = \int_0^R P_{r1} \cdot 2\pi r \, dr$$

$$= (158.71 \times 2\pi) \int_0^{132.28} r \cdot e^{\left(\frac{132.28 - r}{400}\right)} \, dr$$

$$= (158.71 \times 2\pi) \left[r(-400)e^{\left(\frac{132.28 - r}{400}\right)} - \int (-400)e^{\frac{132.28 - r}{400}} \right]$$

$$= (158.71 \times 2\pi) \left[-400r e^{\frac{(132.28 - r)}{400}} - 400^2 e^{\frac{(132.28 - r)}{400}} \right]_0^{132.28}$$

$$= (158.71 \times 2\pi) \left[(-400 \times 132.28 - 400^2) - (0 - 400^2 e^{\frac{132.28}{400}}) \right]$$

$$\text{Forging load} = 9.771 \text{ MN}$$

$$\text{Mean die pressure} = \frac{\text{Load}}{\text{Total Area}}$$

$$= \frac{9.771 \times 10^6}{\pi (132.28)^2} = 177.74 \text{ MPa}$$

Maximum die pressure :

As forging pressure is given by

$$P_{r1} = \sigma_0 e^{\frac{2\mu}{h}(R-r)}$$

For maximum pressure put $r = 0$

$$\Rightarrow \text{Maximum die pressure} = \sigma_0 e^{\frac{2\mu}{h}R}$$

$$= 158.71 e^{\frac{2 \times 0.05}{40} \times 132.28}$$

$$\text{Maximum die pressure} = 220.91 \text{ MPa}$$

Example : 5.14

A circular disc of 200 mm diameter is 100 mm thick is compressed between two dies to a thickness of 50 mm. Determine the maximum die pressure if coefficient of friction is 0.1 and yield strength in compression is 230 MPa.

Solution :

Given

$$\begin{aligned}\text{Initial dia of billet } (D_i) &= 200 \text{ mm} \\ \text{Initial thickness of billet } (h_i) &= 100 \text{ mm} \\ \text{Final thickness of billet } (h_f) &= 50 \text{ mm} \\ \text{Coefficient of friction } (\mu) &= 0.1 \\ \text{Yield strength } (\sigma_0) &= 230 \text{ MPa}\end{aligned}$$

Step I : Calculation of final diameter of billet

as (volume of billet before forging) = (volume of billet after forging)

$$\frac{\pi}{4} \times D_i^2 \times h_i = \frac{\pi}{4} D_f^2 \times h_f$$

$$D_f^2 = D_i^2 \times \frac{h_i}{h_f}$$

$$= 200^2 \times \frac{100}{50}$$

$$D_f = 282.84 \text{ mm}$$

$$\text{Radius } (R_f) = 141.42 \text{ mm}$$

As we know all the forging calculations are done on final dimensions of billet

So, Radius of billet = $R = R_f = 141.42 \text{ mm}$

Height of billet = $h = h_f = 50 \text{ mm}$

as die pressure is given by $P_r = \sigma_0 \cdot e^{\frac{2\mu}{h}(R-r)}$

For maximum pressure $r = 0$

$$\Rightarrow P_{\max} = \sigma_0 \cdot e^{\frac{2\mu}{h} \times R}$$

$$= 230 \times e^{\frac{2 \times 0.1 \times 141.42}{50}}$$

$$P_{\max} = 404.95 \text{ MPa}$$

5.7 ROLLING

As shown in the figure, grain structure of the metal changes when it passes through the rolls. As a result of squeezing the grains are elongated in the direction of rolling and velocity of the material at exit is higher than at the entry. After crossing the stress zone the grains start refining. But this is the case only in the hot rolling. In the cold rolling they tend to retain the shape acquired by them during rolling.

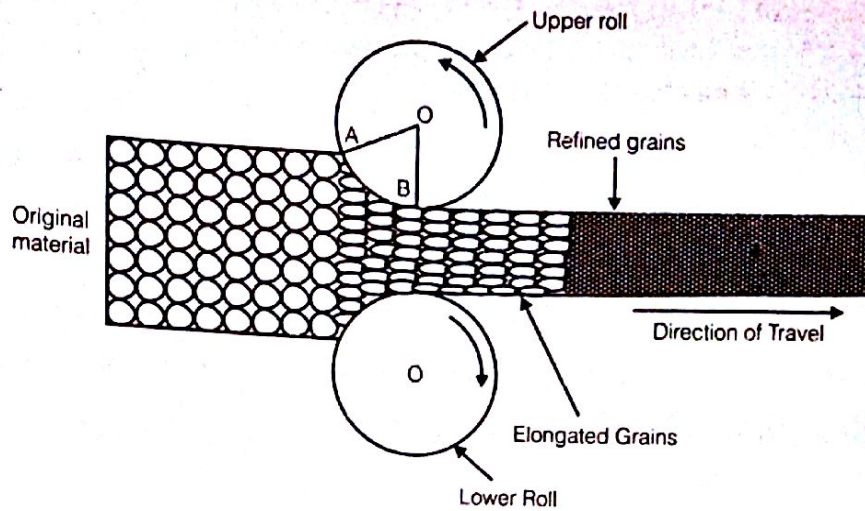


Fig 5.16 : Change of structure during rolling process

The rolls are in contact with the passing metal piece over a sufficient distance represented by the arc AB in the diagram. The angle AOB is called the angle of contact or maximum angle of bite.

5.7.1 Mechanics of Rolling

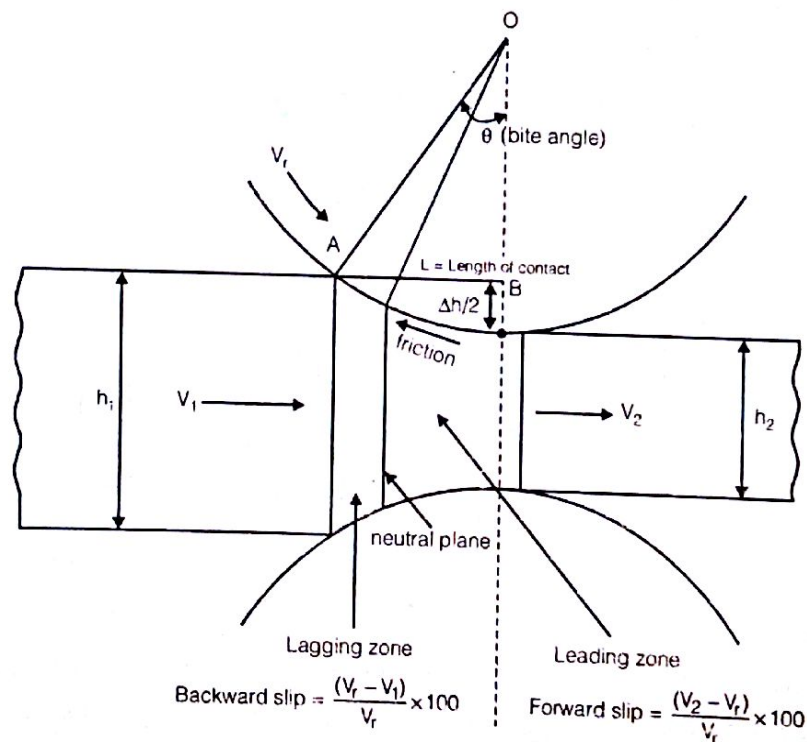


Fig 5.17 : (a) Rolling description

$$\text{Velocity} = \frac{\pi DN}{60}$$

$$\text{Reduction } \Delta h = h_1 - h_2$$

From Figure 5.17(b)

$$L^2 = \left(2R - \frac{\Delta h}{2}\right) \left(\frac{\Delta h}{2}\right)$$

Δh^2 is very small

So

$$L^2 = R \Delta h$$

$$L = \sqrt{R \Delta h}$$

...(29)

From Figure 5.17(b)

$$\frac{\Delta h}{2} = R - R \cos \theta$$

$$\frac{\Delta h}{2} = R(1 - \cos \theta)$$

$$\cos \theta = \frac{R - \frac{\Delta h}{2}}{R}$$

$$\cos \theta = 1 - \frac{\Delta h}{2R}$$

Condition of self entry

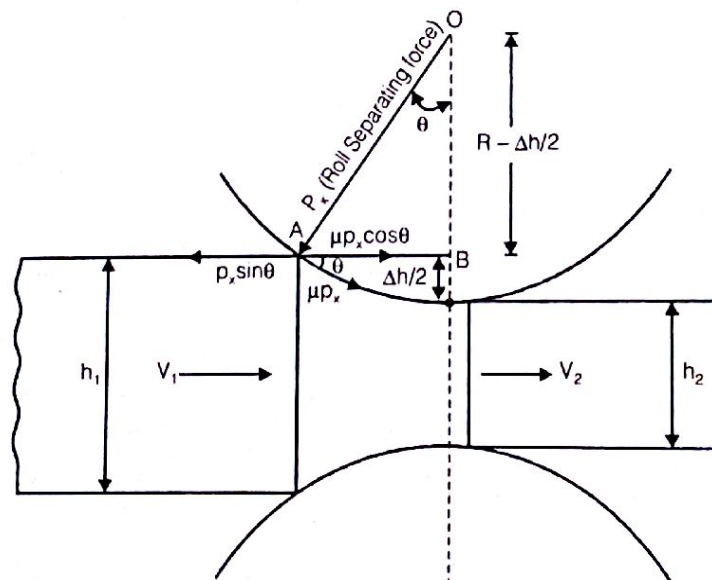


Fig. 5.17 (c)

From figure 5.17 (c) when

$$\mu p_x \cos \theta \geq p_x \sin \theta \quad (\text{for self entry})$$

$$\Rightarrow \mu \geq \frac{\sin \theta}{\cos \theta}$$

$$\Rightarrow \mu \geq \tan \theta$$

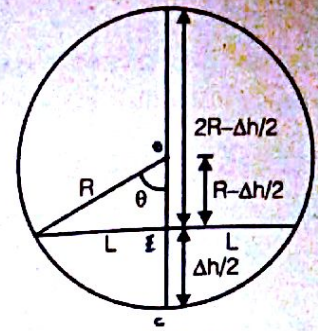


Fig 5.17 (b)

From Fig 5.17(b)

$$\tan \theta = \frac{L}{R - \frac{\Delta h}{2}} = \frac{\sqrt{R \Delta h}}{R - \frac{\Delta h}{2}}$$

From the condition of self entry, we get

$$\mu = \frac{\sqrt{R \Delta h}}{R} = \sqrt{\frac{\Delta h}{R}}$$

$$\Delta h = \mu^2 R \quad \dots(30)$$

At the entry the velocity of material will be lower than the velocity of rolls, so friction will be in the forward direction. There exists a plane in the deformation zone where the velocity of material is equal to the velocity of roll called neutral plane. Beyond this plane the velocity of rolls and the friction will be in the backward direction. The out going plate thickness will be slightly higher than the minimum gap between the rolls due to elastic recovery.

By increasing the coefficient of friction, the neutral plane shifts towards left. By maintaining the same parameters if the thickness of incoming plate increased, external pressure has to be applied at the entry and this shifts the neutral plane towards right. There will be a situation at which neutral plane coincides with the vertical axis so, there will not be any deformation in the material and the roll will slip over the material. This is called rolling limit and the bite angle at rolling limits is called angle of nip.

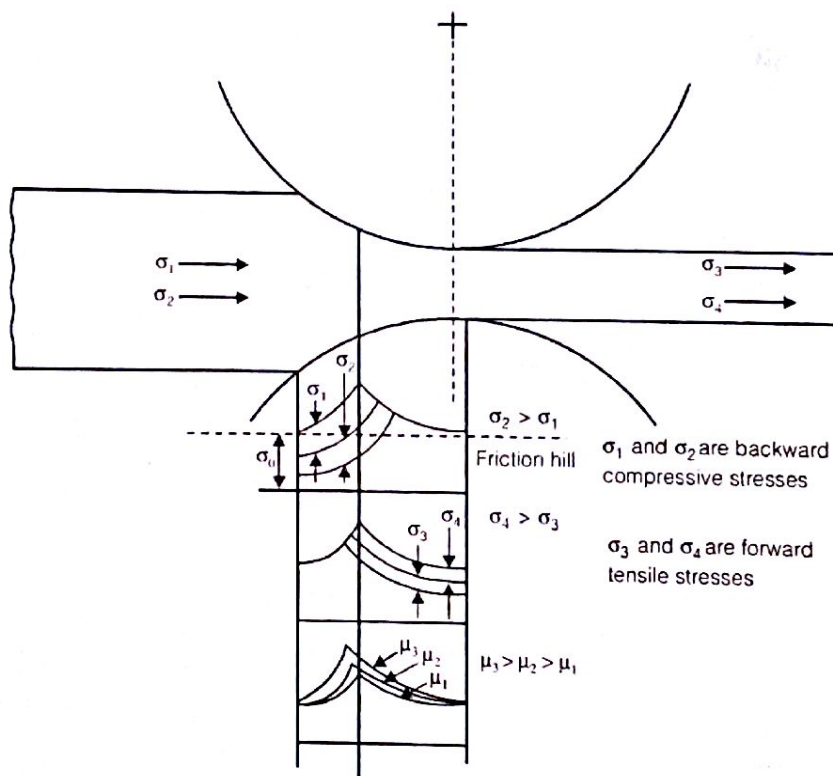


Fig 5.18 : Illustration of friction hill

$$\alpha_n = \text{Angle of nip} = 2\mu \text{ (radians)}$$

$$\alpha_n = 2\mu \times \frac{180}{\pi} \text{ (degrees)}$$

It can be seen from the friction hill that, when the same amount of reduction is given by smaller size rolls lesser amount of rolling load will be required but, there will be a tendency in the roll to deform. This problem can be taken care of by two methods.

5.7.2 Camber rolls

Equal to the deformation of roll, camber is being provided so that when actual deformation is taking place the portion of roll which comes in contact with the material becomes flat. But camber rolls are designed for a particular material and for a particular reduction.

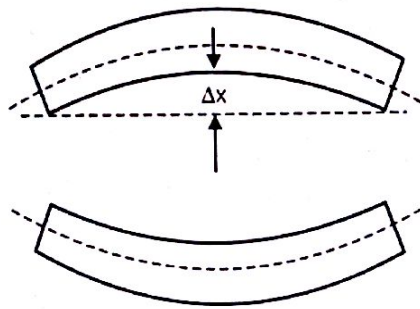


Fig 5.19 : Camber rolls during operation

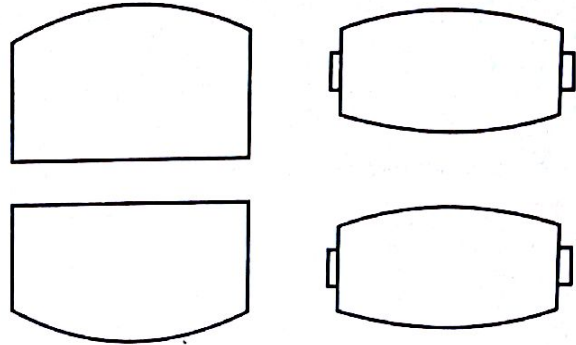


Fig 5.20 : Camber rolls

5.7.3 Back up rolls

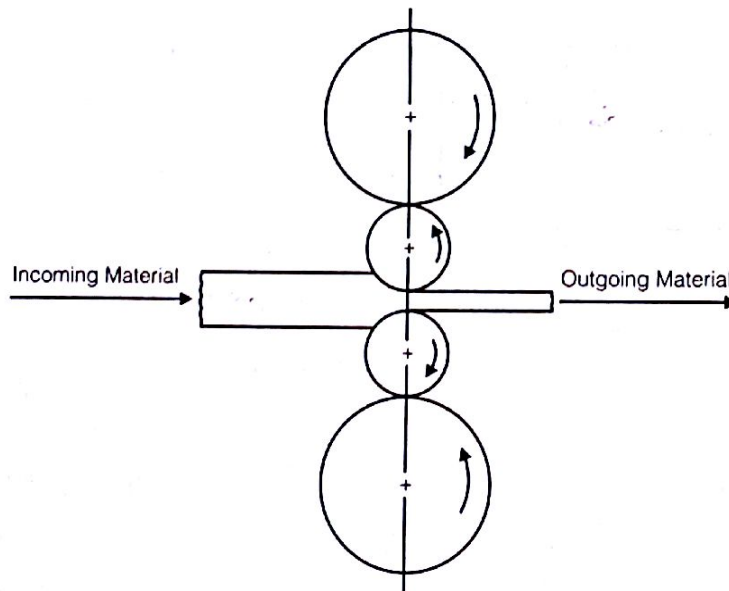


Fig 5.21 : (a) 4 high mill

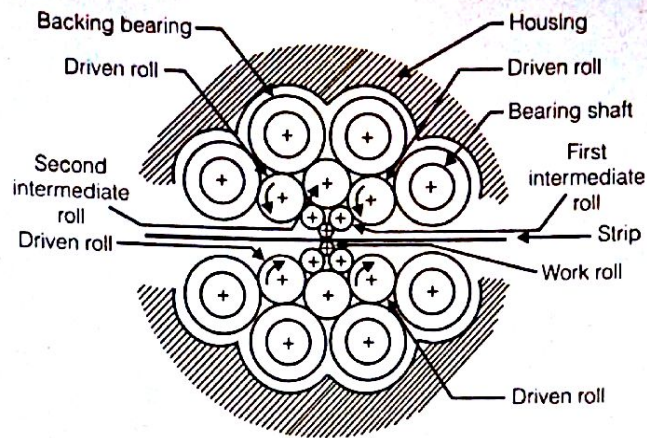


Fig 5.21 : (b) Sandzmer mill

In 4-high mills, bigger rolls are provided for backup and power is given to the smaller rolls. By the variation in % reduction the position of neutral plane will change and hence the direction in which the roll is deforming also changes so in that cluster or sandzmer mills are used.

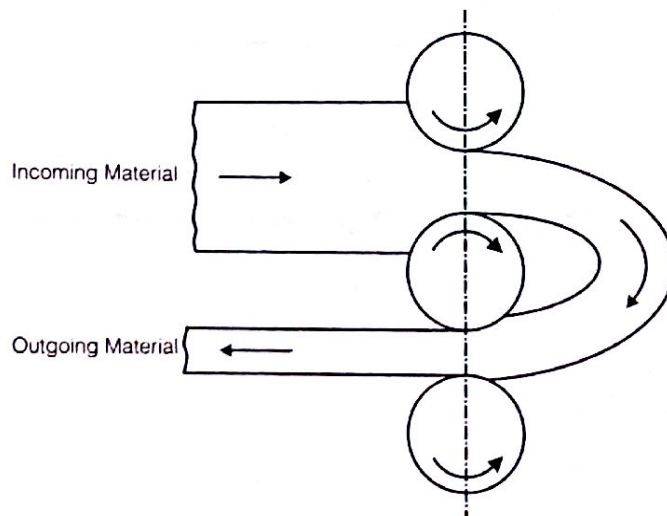


Fig 5.21 : (c) 3 high mills

5.7.4 Three high mill

It is a process of giving 2 stage reduction with the help of 3 rolls. The directions of the rotation of upper and lower rolls are same. But the intermediate roll rotates in a direction opposite to both of these. Although three rolls continuously revolve in the same fixed directions and are never reversed. The work pieces fed in one direction between the upper and middle rolls and reversed direction between the middle and lower rolls.

5.7.5 Planetary Mill

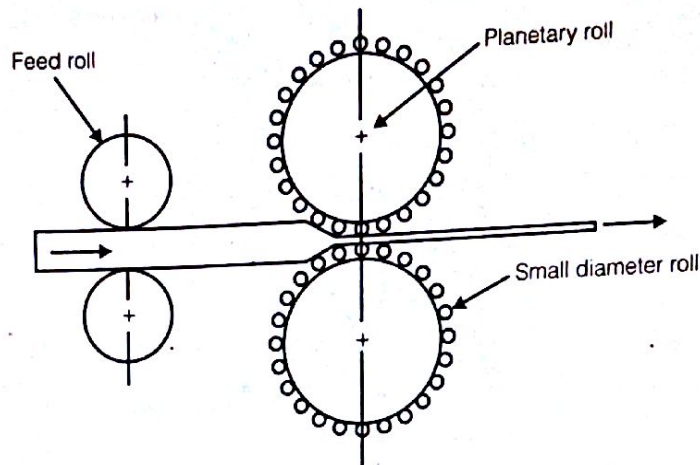


Fig 5.22 : Planetary mill

Over the surface of larger rolls smaller rolls are mounted which rotate in their own axis. Power is given to the larger rolls. Hence there is a rolling limit deformation carried out by a number of pair of rolls in one stage. So a very thick plate can be converted into a thin sheet in one go.

5.7.6 Tandom mill

In tandom rolling the strip is rolled continuously through a number of stands to smaller gauges with each pass. Each stand consists of a set of rolls with its own housing and controls. A group of stands is called train.

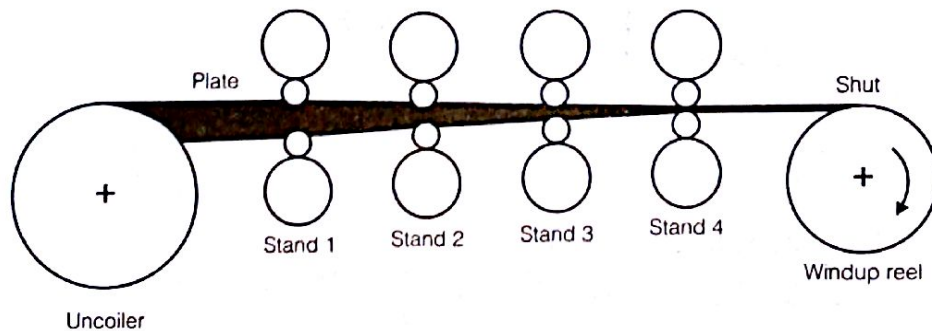


Fig 5.23 : Tandom mill

$$\text{Average rolling load} = \sigma_0 (L \times W)$$

L = Length of Arc of contact

W = width of sheet

5.7.7 Rolling defects

1. **Wavy edges** : These are the result of roll bending. The strip is thinner along its edges than at its centre. Because the edges elongate more than the centre they buckle because of restraining from expanding freely in the rolling direction.
2. **Spread** : In the rolling of plates and sheet having high width to thickness ratio the width of the material remains constant during rolling. With smaller ratios the width increases considerably in the roll gap. This increase in width is called spreading.

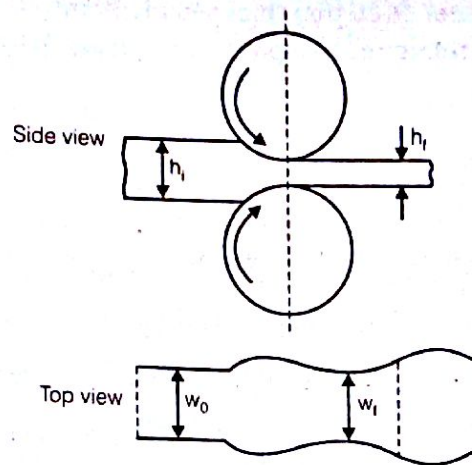


Fig 5.24 : Increase in the width of a strip in flat rolling

3. **Crocodile crack** : Due to weakness at the center sheet bifurcates into two parts. This is called crocodile crack.

5.7.8 Test to calculate the defects

Tensile test specimens are cut 0°, 45° and 90° with the rolling direction. The samples are unloaded before UTS point and the strain ratio is calculated. Higher the value of planer anisotropy more will be the rolling defects like wavy edges. Spread is the increase in width of sheet after rolling.

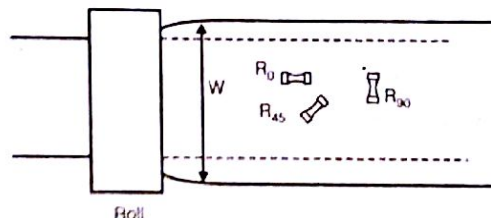


Fig : 5.25

$$\text{Normal anisotropy } (\bar{R}) = \frac{R_0 + 2R_{45} + R_{90}}{4}$$

$$\text{Planar anisotropy } = \Delta R = \frac{R_0 - 2R_{45} + R_{90}}{2}$$

$$\text{where } R = \frac{\text{Width strain}}{\text{Thickness strain}}$$

Formability is the ability of any material to form different shapes. Higher is the value of R (normal anisotropy) more is the formability and more is the value of planar anisotropy larger will be the defects like earing.

When $t < 6\text{mm}$ it is called sheet

When $t > 6\text{mm}$ it is called plate.

Example : 5.15

✓ In a rolling process, sheet of 25 mm thickness is rolled to 20 mm thickness. Roll is of diameter 600 mm and it rotates at 100 rpm. What is the roll strip contact length?

Solution :

Given

$$\text{Initial thickness } (h_1) = 25 \text{ mm}$$

$$\text{Final thickness } (h_2) = 20 \text{ mm}$$

$$\text{Roll diameter} = 600 \text{ mm}$$

$$\text{Speed of rolls} = 100 \text{ RPM}$$

As we know that contact length of roll strip is given by

$$L = \sqrt{R \cdot \Delta h}$$

where

$$R = \text{roll radius} = \frac{600}{2} = 300 \text{ mm}$$

and

$$\Delta h = h_1 - h_2 = (25 - 20) = 5 \text{ mm}$$

Put these values we have

$$L = \sqrt{300 \times 5} = \sqrt{1500} = 38.72 \text{ mm}$$

$$L = 38.72 \text{ mm}$$

Example : 5.16

✓ A 4 mm thick sheet is rolled with 300 mm diameter rolls to reduce thickness without any change in its width. The friction coefficient at the work-roll interface is 0.1. What is the minimum possible thickness of the sheet that can be produced in a single pass?

Solution :

Given

$$\text{initial thickness } (h_1) = 4 \text{ mm}$$

$$\text{roll diameter } (D) = 300 \text{ mm}$$

$$\text{coefficient of friction } (\mu) = 0.1$$

Now let h_2 be the final thickness of sheet after rolling

For single pass without slipping minimum possible thickness mode is

$$(h_1 - h_2) = \mu^2 R$$

where

$$R = \text{radius of roll} = \frac{300}{2} = 150 \text{ mm}$$

$$h_2 = h_1 - \mu^2 R \Rightarrow h_2 = 4 - (0.1)^2 \times 150$$

$$h_2 = 4 - 1.5 = 2.5 \text{ mm}$$

$$h_2 = 2.5 \text{ mm}$$

Example : 5.17

✓ The thickness of a metallic sheet is reduced from an initial value of 16 mm to a final value of 10 mm in one single pass rolling with a pair of cylindrical rollers each of diameter of 400 mm. What is the bite angle in degree?

Solution :

Given

$$\text{initial thickness } (h_1) = 16 \text{ mm}$$

$$\text{final thickness } (h_2) = 10 \text{ mm}$$

$$\text{roll diameter} = 400 \text{ mm}$$

we know that

$$\tan \theta = \sqrt{\frac{h_1 - h_2}{R}}$$

where

θ = Bite angle

and

$$R = \text{radius of roll} = \frac{400}{2} = 200 \text{ mm}$$

$$\tan \theta = \sqrt{\frac{16 - 10}{200}} = 0.1732$$

$$\theta = \tan^{-1}(0.1732) = 9.82^\circ$$

$$\text{Bite angle } (\theta) = 9.82^\circ$$

Example : 5.18

In a single pass rolling operation, a 20 mm thick plate with plate width of 100 mm, is reduced to 18 mm. The roller radius is 250 mm and rotational speed is 10 rpm. The average flow stress for the plate material is 300 MPa. What is the power required for the rolling operation in kW is closest to?

Solution :

Given

initial thickness of plate (h_1) = 20 mm

final thickness of plate (h_2) = 18 mm

width of plate (w) = 100 mm

radius of roll (R) = 250 mm

speed of rolling (N) = 10 RPM

Average flow stress for plate material

$$\sigma_0 = 300 \text{ MPa}$$

Now we know that

$$\text{Force} = \text{Stress} \times \text{Area}$$

$$\text{Force} = \sigma_0(L \times W)$$

where

$$L = \sqrt{R(\Delta h)} = \sqrt{R(h_1 - h_2)}$$

Put values of R , h_1 and h_2 ; we have

$$L = \sqrt{250(20 - 18)} = \sqrt{250 \times 2} = 22.36 \text{ mm}$$

$$L = 22.36 \text{ mm}$$

$$\text{Now force} = 300 \times 22.36 \times 100 = 670800 \text{ N}$$

and we know that

$$\text{power} = \text{force} \times \text{velocity}$$

$$\text{where velocity } (v_r) = \frac{\pi DN}{60}$$

$$v_r = \frac{\pi \times (2 \times 250) \times 10}{60} = 261.79 \text{ mm/s}$$

Now

$$\text{power} = 670800 \times 261.79$$

$$= 175588608 \frac{\text{N} \cdot \text{mm}}{\text{s}} = 175 \text{ k} \frac{\text{Nm}}{\text{s}}$$

$$\text{power} = 175 \text{ kW}$$

5.8 PUNCHING AND BLANKING

Shearing is a metal fabrication process where the flat sheet metal is cut into straight lines. Two blades are forced against each other with a space between them. Generally one of the blades remain stationary. Metal shearing can be performed on sheet, strip, bar, plate, and even angle stock. Bar and angle materials can only be cut to length. However, many shapes can be produced by shearing sheet and plate. Blanking is a metal forming process in which the sheet metal is punched by the die to get the required outer profile of the sheet metal component. During this process the blanking punch penetrates into the sheet metal forcing the profile into the blanking die. The dimensions of the die is equal to the dimensions of the sheet metal component and the clearance is provided on the punch.

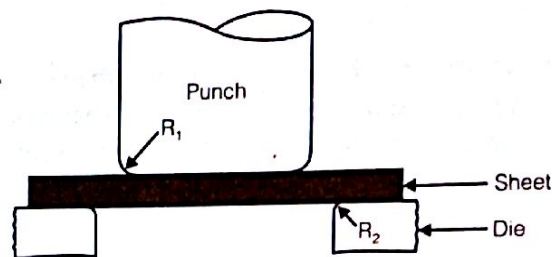


Fig 5.26 : (a) Punching operation

R_1 = punch corner radius

R_2 = Die corner radius

When the pressure on the blank holder is very high, punch and die curvatures are very low and clearance is very small. Sheet metal will shear. When the removed material of the sheet is useful it is called blanking operation and when removed material is a waste it is called punching operation. As Punch covers roll over depth strains will be primarily elastic. Plastic deformation will begin in the burnish depth. After penetration fracture will start and the material will be sheared. More ductile material, larger will be the fracture angle, which produces large size Burrs. To accommodate these large size burrs clearance has to increase.

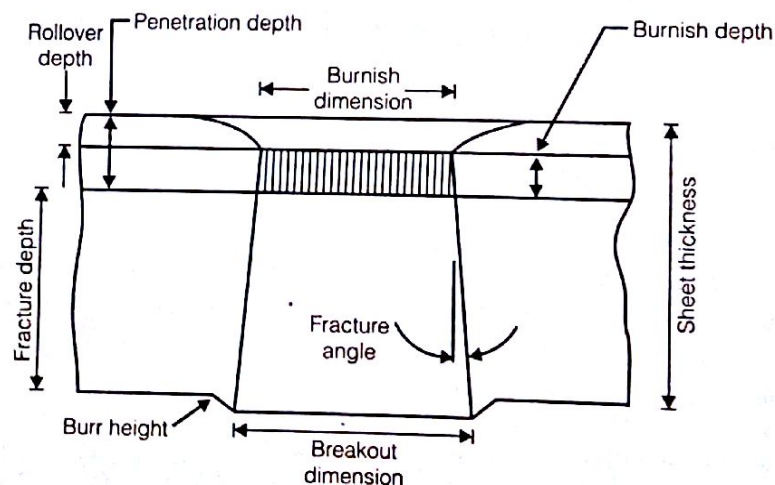


Fig 5.26 : (b) Punched hole

$$\text{Punch load} = \pi D t \times K' \left[\frac{\text{Penetration}}{\text{shear on punch}} \right]$$

Where, K' is the yield strength in shear, D is diameter of hole/blank and t is sheet thickness.

In punching operation punch is exact so clearance is provided over the die and angle of shear is provided over the punch. In blanking operation die is exact so clearance is provided over the punch and angle of shear is provided over the die.

5.9 DEEP DRAWING

Sheet metal forming (also called press working) involves conversion of flat thin sheet metal blanks into parts of desired shape. Sheet metal forming processes like deep drawing, stretching, bending etc. are widely used to produce a large number of simple to complex components in automotive and aircraft industries, household appliances etc. Most of these parts are manufactured using one or more of the sheet metal forming processes. These processes are also called sheet metal stamping operations. In deep drawing, which is also called cup drawing or radial drawing, flat thin sheets (blanks) are formed into cup shaped components by pressing the central portion of the sheet into die opening using a punch to draw the metal into the desired shape.

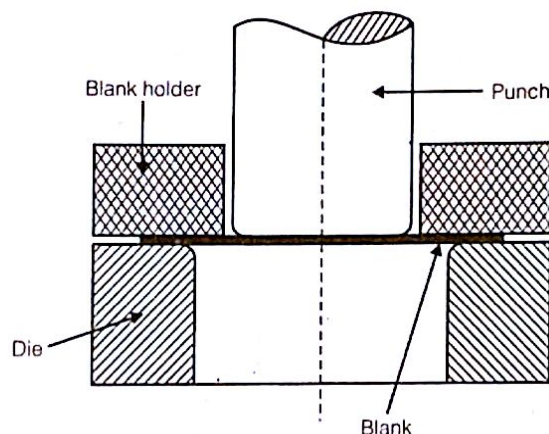


Fig. 5.27 (a)

The blank may be circular or rectangular, or of a more complex outline. Blank holder is loaded by a blank holder force, which is necessary to prevent wrinkling and to control the material flow into the die cavity. The punch is pushed into the die cavity, simultaneously transferring the specific shape of the punch and the die to the blank. During the forming stage the material is drawn out of the blank holder-die region and the material is subjected to compressive and tensile stresses in this portion. When a very high blank holding force is applied, the deep drawing process becomes a stretching process.

In stretch forming or stretching, the flange of the flat blank is securely clamped. In some cases, the material is fixed under the blank holder and the remaining part of the blank is formed over a tool. Normally a rigid punch is used to form the part. Stretching is characterized by bi-axial tensile stresses leading to significant thickness reduction in the deformed portion.

Bending is the plastic deformation of metals about a linear axis (called the bending axis) with little or no change in the surface area. The bending process is used not only to form parts such as angle sections, flanges, seams and corrugations, but also to impart stiffness to the part by increasing its moment of inertia. It is the most common type of deformation that occurs in almost all sheet forming operations.

In deep drawing operation, bending of sheet takes place over the die curvature. The bend zone experiences localized strains which are tensile on the outside of the neutral axis and compressive on the inside.

In deep drawing, the majority of the deformation occurs in the flange of the cup. The metal is subjected to three different types of stress systems. These stresses have influence over thickness variation in drawn cup. The primary deformation occurs in the flange of the deforming cup which undergoes radial tension and circumferential compression. Because of this, thickness increases in the flange portion. The second deformation zone is the bending around the die radius while the third deformation zone is the uni-axial stretching (plane strain) in the cup wall, which causes thinning of the metal. In the cup bottom, which is subjected to biaxial tension, the thickness is more or less equal to the initial sheet thickness.

The draw ratio (DR) of a deep drawing process is calculated as the ratio of blank diameter to the cup diameter. For achieving very high draw ratio, redrawing and ironing or annealing between draws is performed. The maximum draw ratio that can be obtained under perfect deep drawing conditions is called limiting draw ratio (LDR). The LDR is considered a good measure of drawability of a material.

In conventional deep drawing the force on the punch required to produce a cup is the summation of the force required for deformation, the friction force and the ironing force (if present). When the punch force in deep drawing of ductile metals increases beyond a certain limit, failure occurs in the cup wall due to tensile stretching and it generally takes place at the transition between the punch profile region and the punch cylindrical region. The force needed to cause deformation is applied through a punch at the central portion of the blank. This force is transmitted through the cup wall to the flange. As the blank size increases, there is an increase in the total force and if the total force exceeds beyond a certain value, fracture occurs in the cup wall. This puts a limit on the blank size that can be successfully drawn into a cup without failure.

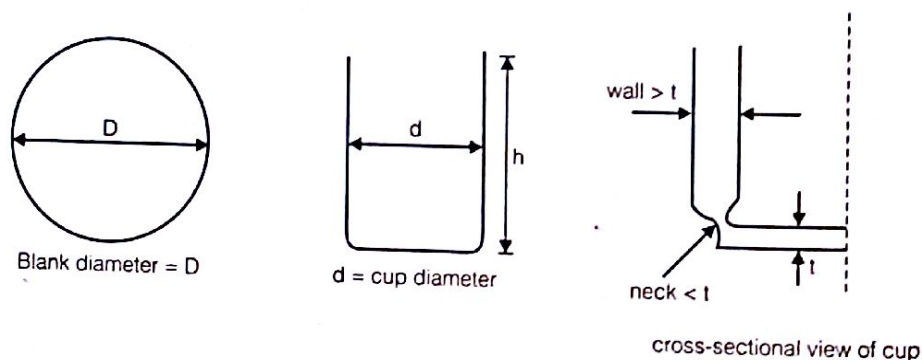


Fig 5.27 : Deep drawing operation

$$\frac{D}{d} = \text{Draw ratio}$$

$$\frac{\pi}{4} D^2 = \frac{\pi}{4} d^2 + \pi d h$$

$$\text{Limiting draw ratio} = \frac{D_{\max}}{d}$$

$$\text{Die-corner radius} = 10 t$$

$$\text{Punch corner radius} = 6 t$$

$$\text{Clearance} = (1.2 \text{ to } 1.4) t$$

$$\text{Blank Holding Pressure} = 2\% \text{ of yield strength}$$

Thickness in the drawn cup at the punch corner will be lower because maximum load is appearing on the material in this region. Since compressive hoop stress is appears in the flange region so thickness of the drawn cup on wall region increases. As the diameter of blank increases thickness of the drawn cup in the punch corner region will decrease. Once this thickness reaches a particular value fracture will appear in the drawn cup. The maximum diameter of the blank that can be drawn safely without any fracture is called limiting draw ratio (LDR) which is an indicator of formability of material. In any material larger the value of, work hardening exponent 'n', higher will be the formability of material. Larger thickness sheets will exhibit larger value of LDR.

5.9.1 Redrawing

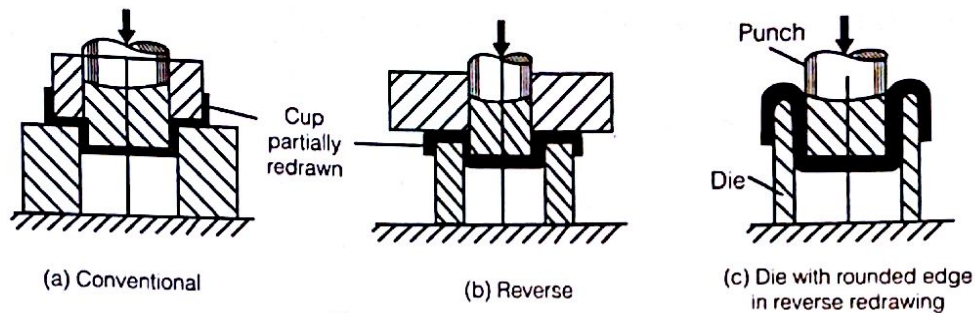


Fig 5.28 : Redrawing operation

Redrawing is a process of drawing already drawn component to increase LDR. Beverage cans are produced in three redrawing stages and two ironing stages. When the redrawing is performed near LDR, Step rings will appear in the drawn component. In conventional redrawing operation the material bends in the opposite direction around the blank holder and the die corners. In the reverse drawing operation the material bends in only one direction namely along the outer and the inner die corners. Since some amount of strain hardening takes place during the initial operation, annealing is normally advised before commencing the redrawing operation.

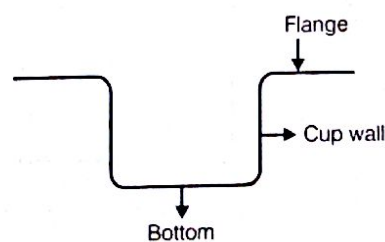
5.9.2 Analysis of deep drawing

There will be three loads acting during deep drawing operation i.e. in the Flange, bending and pulling over die curvature. Total load will be addition of these three loads.

Assuming that σ_r and σ_θ are the principle stresses and since σ_θ is compressive so

$$\Rightarrow \frac{d\sigma_r}{dr} + \left(\frac{\sigma_r + \sigma_\theta}{r} \right) = 0$$

$$\Rightarrow \frac{d\sigma_r}{dr} = \frac{-2K'}{r}$$



R = Radius of blank

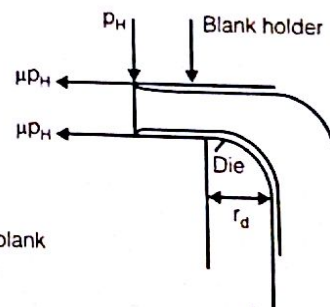


Fig : 5.29 (a)

by integrating

$$\Rightarrow \int d\sigma_r = \int \frac{-2K'}{r} dr$$

$$\Rightarrow \sigma_r = -2K' \ln r + c_1 \quad \dots(31)$$

Boundary conditions at $r = R$, $\sigma_r = \frac{\mu P_H}{\pi R t}$

Also $\sigma_r + \sigma_\theta = 2K'$

Substituting the boundary conditions in equation (31)

$$\sigma_r = 2K' \ln \left(\frac{R}{r} \right) + \frac{\mu P_H}{\pi R t} \quad \dots(32)$$

Upto section ① as shown in Fig. 5.29 (b)

$$r = \left(r_p + \frac{t}{2} + r_d \right) = R_d$$

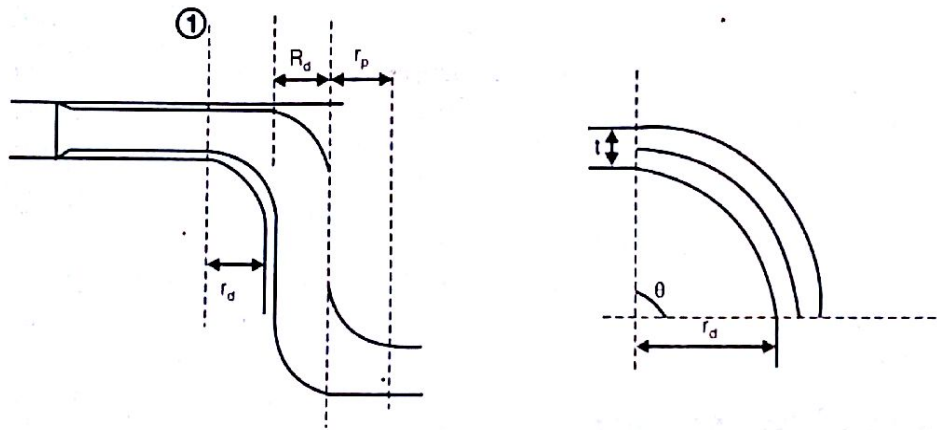


Fig : 5.29 (b)

Drawing pressure up to ① (flange)

$$\sigma_r = \frac{\mu P_H}{\pi R t} + 2K' \ln \left(\frac{R}{r} \right)$$

Punch pressure required to bend the sheet

$$\text{Maximum strain} = \frac{(r_d + t)\theta - \left(r_d + \frac{t}{2} \right)\theta}{\left(r_d + \frac{t}{2} \right)\theta}$$

$$\left(r_d + \frac{t}{2} \right) = r_n = \text{radius of neutral plane.}$$

$$\text{Maximum strain} = \frac{t}{2r_n}$$

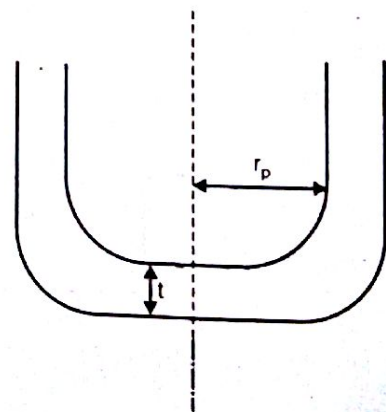


Fig 5.29 : (c)

$$\text{Average strain} = \frac{0 + \frac{t}{2r_n}}{2} = \frac{t}{4r_n}$$

$$\text{Pressure required for bending} = \frac{t}{4r_n} \times \sigma_0$$

Total pressure required by the punch up to bending of sheet

$$\sigma_w = \frac{\mu p_H}{\pi R t} + 2K \ln \left(\frac{R}{R_d} \right) + \frac{\sigma_0 t}{4r_n} \quad \dots(33)$$

Since sheet metal is pulled over the die curvature and if the angle of contact between sheet and die is θ , total pressure required by the punch to draw the cup is

$$\sigma_w = \left[\frac{\mu p_H}{\pi R t} + 2K \ln \left(\frac{R}{R_d} \right) + \frac{\sigma_0 t}{4r_n} \right] e^{\mu \theta} \quad \dots(34)$$

$$\text{Punch load} = \sigma_w \times 2\pi r_p t \quad \dots(35)$$

Example : 5.19

If a fully work hardened Aluminium blank of 100 mm diameter and 1.2 mm. Sheet has a mean flow stress of 350 MPa. It is deep drawn to a cylindrical cup of 50 mm mid wall diameter. The blank holding force is 30 kN, coefficient of friction is 0.1. Take the die curvature radius as 8 times the sheet thickness. Determine the final cup height and appropriate load.

Solution :

Given data

$$R = 50 \text{ mm}$$

$$t = 1.2 \text{ mm}$$

$$\sigma_m = \sigma_0 = 350 \text{ MPa}$$

$$d_p = 50 \text{ mm}$$

$$p_H = 30 \text{ kN}, \mu = 0.1$$

$$r_d = 8t$$

$$R_d = 25 + \frac{1.2}{2} + (8 \times 1.2)$$

$$R_d = 35.2 \text{ mm}$$

$$r_n = r_d + \frac{t}{2}$$

$$r_n = 9.6 + 0.6$$

$$r_n = 10.2 \text{ mm}$$

Height can be found by

$$\pi R^2 = \pi r_d^2 + 2\pi r_d h$$

$$(50^2) = (25)^2 + 2(25)h$$

$$h = 37.5 \text{ mm}$$

$$\sigma_w = \left[\frac{\mu p_H}{\pi R t} + 2K \ln \left(\frac{R}{R_d} \right) + \frac{\sigma_0 t}{4r_n} \right] e^{\mu \theta}$$

$$\Rightarrow \sigma_w = \left[\frac{0.1 \times 30 \times 10^3}{\pi \times 50 \times 1.2} + 350 \ln \frac{50}{35.2} + \frac{1.2}{4 \times 10.2} \times 350 \right] e^{\frac{0.1 \times 90 \times \pi}{180}}$$

$$\begin{aligned} \Rightarrow \sigma_w &= 174.38 \\ \text{punch load} &= \sigma_w \times 2\pi r_p t \\ &= 174.38 \times 2\pi \times 25 \times 1.2 \\ &= 32.85 \text{ KN} \end{aligned}$$

Example : 5.20

A Cylindrical cup without flange is to be drawn from a 2 mm thick sheet. The cup shall have 15 mm diameter and 40 mm height. Reduction ratio in the first and subsequent draws may not exceed 40% and 15% respectively. Determine the blank size and the number of draws necessary.

Solution :

Approximate blank diameter can be calculated by equating the surface area (assuming the variation in thickness to be insignificant)

$$\frac{\pi}{4} D^2 = \frac{\pi}{4} d^2 + \pi d h$$

where D is diameter of blank, d is diameter of cup and h is cup height

$$\frac{\pi}{4} (D^2) = \frac{\pi}{4} (15)^2 + \pi (15) (40)$$

$$D = 51.23 \text{ mm}$$

$$\text{So the overall ratio} = \frac{D}{d} = 3.41$$

Let us say d_1 is the diameter of cup after first draw and it will be the blank diameter for 2nd draw and so on. So overall draw ratio can be written as

$$\underbrace{\frac{D}{d_1}}_{1 \text{ stage}} \times \underbrace{\frac{d_1}{d_2} \times \dots}_{n-1 \text{ stages}} = 3.41$$

Since 40% reduction can be given in the first draw, so

$$d_1 = 0.6 D$$

and 15% reduction can be given in the subsequent draws. So

$$d_2 = 0.85 d_1 \text{ and so on.}$$

$$\text{So } \frac{1}{0.6} \times \left(\frac{1}{0.85} \right)^{n-1} = 3.41$$

$$(n-1) \ln \left(\frac{1}{0.85} \right) = \ln (2.049)$$

$$= 0.717$$

$$n-1 = 4.41$$

$$n = 5.41$$

So total 6 draws are necessary.

5.9.3 Measuring of formability

There are some tests by which we can measure the formability.

1. Cupping test

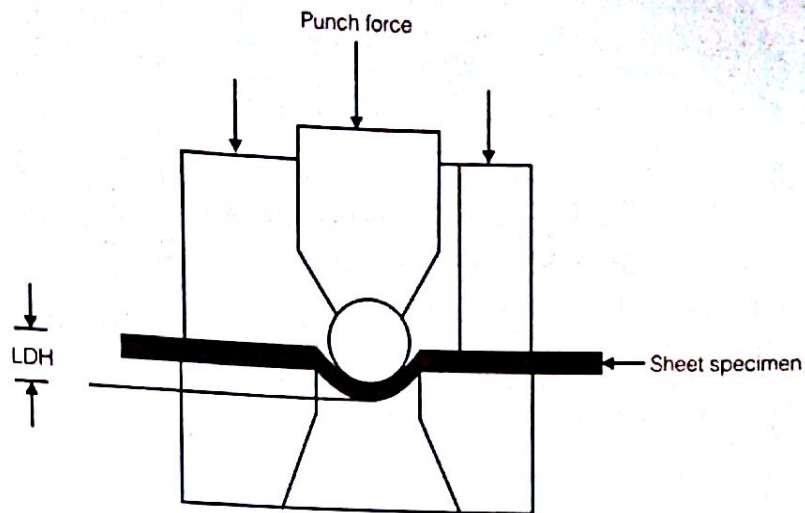


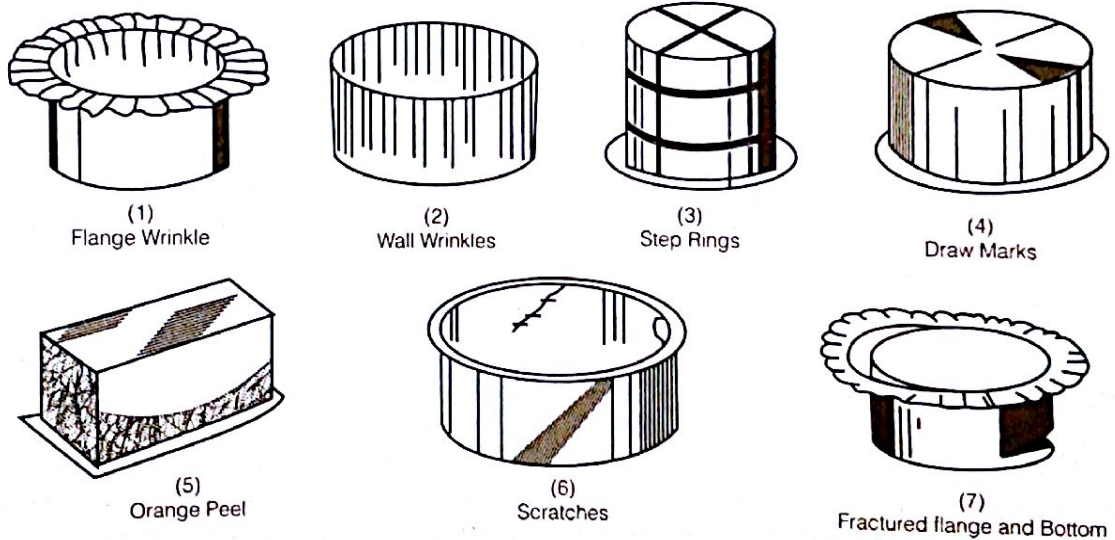
Fig 5.30 : Cupping test

When punching, after some time necking will appear so before the neck has appeared how much the amount of height it is moved is known as Limiting Dome Height (LDH), a measure of formability. Sheet will be restricted to move by draw bead. Higher is LDH more will be formability of shut material.

2. Formability limit diagrams

In deep drawing process when we take circles on the space of upper portion and deform the material, there it will form an ellipse and the major and minor axis will form. By using that a graph is formed between major and minor strains of deformed circle, that is called Formability limit diagrams.

5.9.4 Common defects in deep drawing



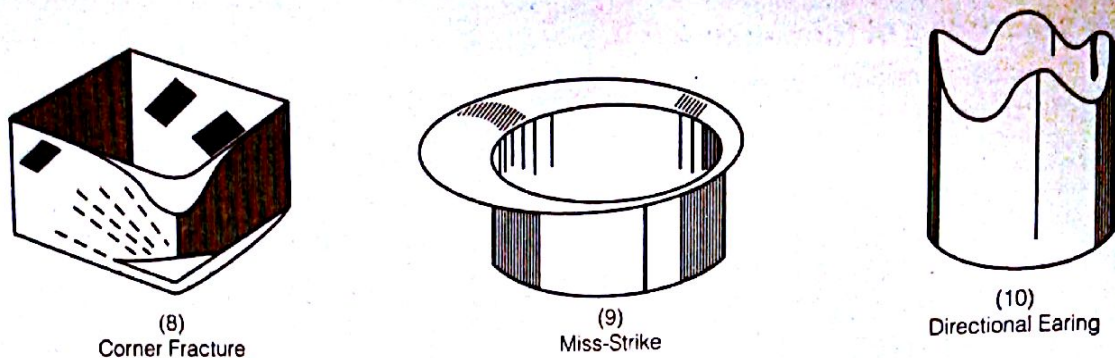


Fig 5.31 : Deep Drawing Defects

Wrinkling occurs in the flange when compressive stresses in the circumferential direction reach a critical point of instability. It can occur in regions where the work piece is unsupported or when the blank holding force is insufficient. Wrinkling defect is shown in Fig. 5.31 (1) and (2). The wrinkling can be prevented by increasing blank holder force and by using a draw bead. The draw bead bends and unbends the work piece material as it passes through the blank holder. This bending over the bead increases the radial tensile stresses and thus reduces the possibility of wrinkling.

As discussed in the previous section that to increase the draw ratio of the material Re-drawing operation is being performed. When Re-drawing is performed near the LDR value, step rings Fig. 5.31 (3) appears in the drawn cup. These step rings appears at the position of neck. To avoid this defect, redrawing operation is performed at a lower value of draw ratio.

Due to the improper finish of the die surface, draw marks Fig. 5.31 (4) appears on the drawn cup. Surface of the die generally deteriorates generally due to improper lubrication between the blank and the die. It should be noted that higher will be the draw ratio when the punch is made rough and die is made smooth.

Orange peel Fig. 5.31 (5) appears in the drawn cup due to coarse grain structure of the drawn material and it can be avoided by refining the grain structure of material. Heavy scratches over the drawn cup Fig. 5.31 (6) may appear due to appearance of yield point phenomenon in the material. So the sheet material must be consumed within the strain aging time of the material.

Fracture [Fig. 5.31 (7) and (8)] occurs when the sheet metal is subjected to strains exceeding the safe strain limits of the material. For ductile sheets this fracture usually occurs near the punch corner. These fractures appears when the draw ratio of the material exceeds LDR or when the blank holding force is more then the required.

Due to non-symmetric placement of blank over die, the defect called mis-strike Fig. 5.31 (9) appears in the drawn cup.

Deep drawing of anisotropic sheets results in a drawn cup with uneven top edge i.e. some kind of ears are formed at the top as shown in Fig. 5.31 (10). This defect is called earing and it is because of planar anisotropy of the blank material. As discussed earlier, ironing is performed to make the thickness of drawn cup uniform. Excessive ironing causes burnishing over the wall region of the drawn cup.

5.10 BENDING

Bending is the cold working process involving plastic deformation in which the total surface area remains constant. In bending the outer fibers of the metal are in tension while the inner fibers are in compression. After bending when the load is removed from work piece, the extent of bending will decrease because of elastic recovery which is called Spring back, this is because materials

have finite modulus of elasticity. Bending can be defined as a process of fabrication of a sheet metal by uniform straining of material around a straight axis which lies in the neutral plane and normal to the lengthwise direction of the sheet or strip. These processes involve a punch and die arrangement. The punch hits the blank and pushes it inside the die cavity which gives the blank as shape of the die. The shape of punch and die play an important role in giving shape to the blank. Sheet metal bending process takes place with the help of a press. Apart from using punch and dies we also use grippers that hold the part during and in between the process. There are various types of process that are used in bending:

- (a) **Air bending** : Air bending is one of the most common methods that are used for sheet metal bending process. In this process the punch only touches the blank that is sufficient to give it the required shape and the angle. In other words the punch doesn't traverse till the end of the die cavity. After the punch travels back, the sheet metal springs back and is of lesser bend than the punch. In air bending process there is no need to change the dies and other necessary equipments to achieve different bend angles as the bend angles depend upon the punch stroke. Also smaller forces are required to bend the sheets but it does require accurate control of punch stroke to achieve required bend angles.
- (b) **Bottoming** : In bottom bending process, the punch bottoms the blank into the die cavity. The amount of spring back is very less in this method. The forces involved are higher (approximately 50-60% more) than air bending.
- (c) **Coining** : Coining is bending process where we bottom the blank and apply compressive stress to increase the amount of plastic deformation of the bent region. This helps in reducing the springback. The inner radius of the workpiece should be 0.75 times the material thickness. Very high forces are required and hence large capacity machines are used. 5 to 8 times the tonnage of the air bending are required. This increases the machine cost rapidly but extremely high precision bend is achieved due to elimination of springback.
- (d) **Other bending processes**: In V-Bending process the clearance between the punch and die is constant. It is taken as the sheet thickness itself. U-bending is a process where we get two parallel bending axis in the same operation. A backing pad is used to force the sheet contacting with the sheet bottom. Around 30% of force is required at the pad where the sheet bottom comes in contact with the pad. The type of bending process which includes bending of only some portion of the sheet is called flanging. The length of flange and the angle of bend can be adjusted accordingly.

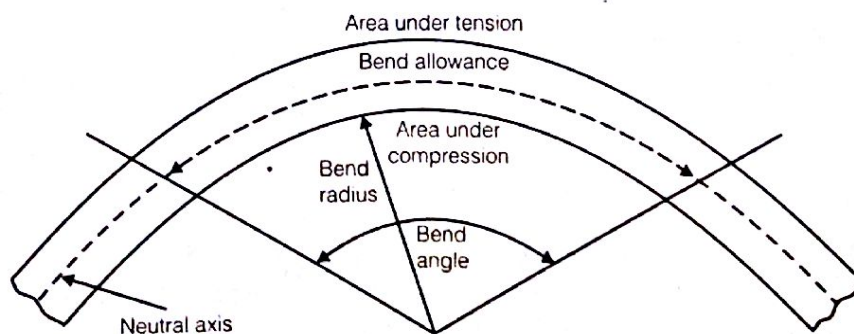


Fig 5.32 : Bending operation

Bend allowance : The length of neutral axis in the curvature region of bend is called bend allowance. In order to estimate the required flat work piece length to make a bend, calculation of bend allowance is essential.

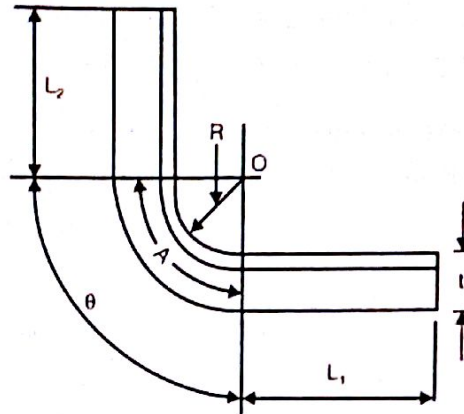


Fig 5.33 : Schematic of bend allowance.

$$\text{Bend allowance} = \theta (R + Kt)$$

t = sheet thickness

θ = angle in radians

R = bend radius

K = stretch factor

= 0.33 when $R < 2t$

= 0.5 when $R \geq 2t$

It is the length of neutral axis in the bend region.

Notching : It is complete removal of small portion of material on the edge of sheet metal.

Lancing : It is creating a tab on the edge without removal of material.

Slitting : It is creating a tab in the middle of sheet.

Nibbling : By using a small punch and die assembly the process of creating a profile is called nibbling.

Perforating : It is a process of producing large number of holes in the sheet metal.

Parting : shearing the sheet into two or more pieces.

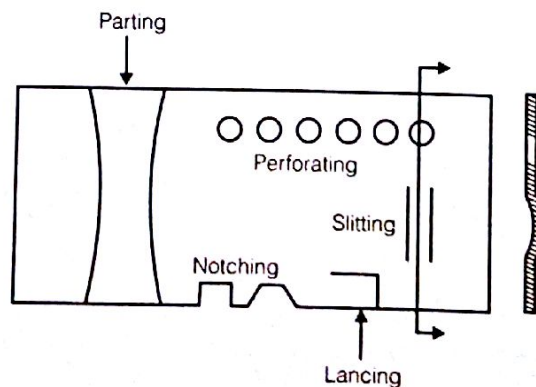


Fig 5.34 : (a) Various operations in forming

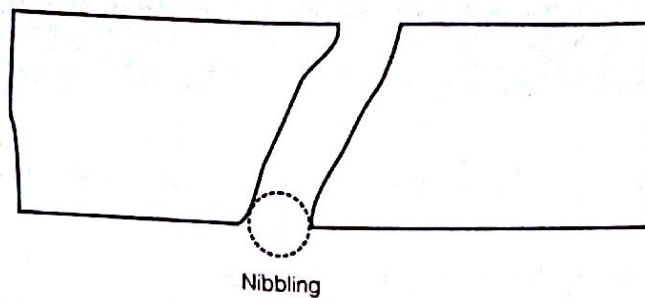


Fig 5.34 : (b)

Types of dies:

1. **Simple die** : On these dies one operation is being performed on one station in a single stroke.
2. **Compound die** : When multiple operations can be performed on a single station in single stroke is called compound die.
3. **Progressive die** : When multiple operations can be performed on multiple stations in a single stroke such dies are called progressive dies.

POINTS TO PONDER

Aging: A change in material property or properties with time.

Anisotropy: Variations in one or more physical or mechanical properties with direction.

Bendability: The ability of a material to be bent around a specified radius without fracture.

Bend Radius: The radius measured on the inside of a bend which corresponds to the curvature of a bent specimen or the bent area in a formed part.

Bend Test: Evaluation of a sheet metal's response to a bending operation, such as around a fixed radius tool.

Blaxial Stretchability: The ability of sheet material to undergo deformation by loading in tension in two directions in the plane of the sheet.

Blank: The piece of sheet metal, produced in cutting dies, that is to be subjected to further press operations. A blank may have a specific shape developed to facilitate forming or to eliminate a trimming operation subsequent to forming.

Blank Holder: The part of a forming die which holds the blank by pressure against a mating surface of the die to control metal flow and prevent wrinkling. The blank holder is sometimes referred to as "Holddown" or binder area. Pressure is applied by mechanical means, springs, air, or fluid cushions. The pressure exerted by the blank holder against the blank. This is normally adjustable to control metal flow during the drawing.

Blanking: The act of cutting a blank.

Bulge Test: A test wherein the blank is clamped securely around the periphery and by means of hydrostatic pressure the blank is expanded. The blank is usually grinded so that the resulting strains can be measured. This test is usually performed on large blanks of 8-12 inches diameter.

Coining: A process of cold forming metals, in which the metal is shaped between two dies in such a manner as to fill the depression of both sides in relief by displacement of the material.

Cupping: A press forming operation in which a cup-shaped part is produced from sheet metal. Cupping is often the first operation in the production of a complex deep-drawn part.

Cup Test: A formability test in which a sheet blank is drawn or stretched into a hemispherical or cylindrical shape. Variations in blank diameter, cup height or forming load are utilized to evaluate sheet formability.

Deep Drawing: In drawing operation, where a part is produced from a blank by the action of a punch in which the sheet is pulled into a die cavity and the flange of the blank is compressed in the circumferential direction. The area directly under the punch remains undeformed.

Drawability: The ability of a sheet to form cup-shaped parts by the action of a punch under conditions that cause the flange or a portion of the flange to be drawn into the die cavity.

Draw Bead: A ridge constructed around a portion of a die cavity to partially restrain metal flow. A groove in the mating blankholder allows die closing. Sometimes called Die Bead.

Erichsen Test: A test in which a piece of sheet metal, restrained except at the center, is deformed by a spherical ended plunger until fracture occurs. The height of the cup in millimeters at fracture is a measure of the ductility.

Forming Limit Diagram: An empirical curve showing the biaxial strain levels beyond which failure may occur in sheet metal forming. The strains are given in terms of major and minor strains measured from deformed circles, previously imprinted into the undeformed sheet.

Fukui Cup Test: A cupping test combining stretchability and drawability in which a roundnosed punch draws a circular blank into a conical shaped die until fracture occurs at the nose. Various parameters from the test are used as the criterion of formability.

Ironing: Forming between dies whose side-wall clearance is less than the sheet metal thickness such that a thinning action occurs. This usually takes place in the side walls of deep-drawn parts where the inflow of metal from the flange tends to thicken or wrinkle; subsequent ironing produces a more uniform wall thickness.



PRACTICE QUESTIONS

1. Assertion(A) : In a two high rolling mill there is a limit to the possible reduction in one pass

Reason(R) : the reduction possible in the second pass is less than that of first pass

- (a) both A and R are individually true and R is correct explanation of A
- (b) both A and R are individually true and R is not correct explanation of A
- (c) A is true but R is false
- (d) A is false R is true

2. Rolling very thin strips of mild steel requires

- (a) large diameter rolls
- (b) small diameter rolls
- (c) high speed rolling
- (d) rolling without a lubricant

3. In rolling process roll separating force can be decreased by

- (a) reducing roll diameter
- (b) increasing roll diameter
- (c) providing back up rolls
- (d) increasing the friction between rolls and metal

4. Consider the following characteristic of a rolling process

- 1. Shows work hardening effect
- 2. Surface finish is not good
- 3. Heavy reduction in areas can obtained

Which of these characteristics associated with hot rolling?

- (a) 1 and 2
- (b) 1 and 3
- (c) 2 and 3
- (d) 1,2 and 3

5. Assertion (A) : Rolling require high friction which increases force and time consumption

Reason (R) : To prevent damage to the surface of rolled products lubricant should be used

- (a) both A and R are individually true and R is correct explanation of A
- (b) Both A and R are individually true and R is not correct Explanation of A
- (c) A is true but R is false
- (d) A is false R is true

6. Which of the following assumptions are correct for rolling

- 1. the material is plastic
- 2. the arc of contact is circular with radius greater than radius of roll
- 3. coefficient of friction is constant over the arc of contact and acts in one direction throughout the arc of contact

Select the correct answer using the codes given below

- (a) 1 and 2
- (b) 1 and 3
- (c) 2 and 3
- (d) 1,2 and 3

7. A strip is to be rolled from thickness of 30 mm to 15 mm using a two high mill having rolls of diameter 300 mm the coefficient of friction for unaided bite should nearly be

- (a) 0.35
- (b) 0.5
- (c) 0.25
- (d) 0.07

8. In one setting of rolls in a 3-high rolling mill one gets

- (a) one reduction in thickness
- (b) two reductions in thickness

- (c) three reductions in thickness
(d) two or three reductions in thickness depending upon setting
9. In a rolling operation the maximum draft is given by (r = radius of coil, μ is coefficient of friction)
- (a) μR (b) $\mu\sqrt{R}$
(c) $\mu^2 R^2$ (d) $\mu^2 R$
10. Flash and Gutter are provided in drop forging dies at the following stage
- (a) blocking (b) preforming (Edging)
(c) finishing (d) fullering
11. In rolling a strip between two rolls, the position of the neutral point in arc of contact does not depends on
- (a) amount of reduction (b) diameter of rolls
(c) coefficient of friction (d) material of rolls
12. A wide strip is rolled to a final thickness of 6.35 mm with a reduction of 30% the roll radius is 50cm and coefficient of friction is 0.2 the arc of contact is
- (a) 0.5 radians (b) 0.0738 radians
(c) 0.0123 radians (d) 0.0235 radians
13. The thickness of a metallic sheet is reduced from initial value of 16mm to a final value of 10 mm in one single pass rolling with a pair of cylindrical rollers each of diameter 400 mm the bite angle in degrees will be
- (a) 5.936 (b) 7.936
(c) 8.936 (d) 9.936
14. Consider the following statements:
- Assertions (A) :** While rolling metal sheet in rolling mill the edges are sometimes not straight and flat but are wavy.
Reason(R) : Non uniform mechanical properties of flat material rolled out result in waviness of edges
- (a) both A and R are individually true and R is correct explanation of A
(b) both A and R are individually true and R is not correct explanation of A
(c) A is true but R is false
(d) A is false R is true
15. A 4mm thick sheet is rolled with 300 mm diameter rolls to reduce thickness without any change in width the friction coefficient at the work roll interface is 0.1 the minimum possible thickness of the sheet that can be produced in single pass is
- (a) 1.0 mm (b) 1.5 mm
(c) 2.5mm (d) 3.7mm
16. Which one of the following is advantage of forging
- (a) good surface finish (b) low tooling cost
(c) close tolerance (d) improves physical property
17. Drop forging is used to produce
- (a) small components (b) large components
(c) identical components in large number (d) minimum size components

18. Consider the following statements

Assertion (A) : In drop forging besides the provision for flash provision is also made in forging die for additional space called gutter

Reason (R) : The gutter helps to restrict the flow of metal thereby helping to fill thin ribs and bases in the upper die

- (a) both A and R are individually true and R is correct explanation of A
- (b) both A and R are individually true and R is not correct explanation of A
- (c) A is true but R is false
- (d) A is false R is true

19. Match **List-I** (Products) with **List-II** (Processes) and select the correct answers with the codes given below

List-I

- A. MS angles and channels
- B. Carburettors
- C. Roof trusses
- D. Gear wheels

List-II

- 1. Welding angles and channels
- 2. Forging
- 3. Casting
- 4. Rolling

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	4	3	2	1
(c)	1	2	4	3
(d)	4	3	1	2

20. Which of the following process is most commonly used for forging of bolt heads of hexagonal shape

- (a) closed die drop forging
- (b) open die upset forging
- (c) close die press forging
- (d) open die progressive forging

21. Match **List-I** with **List-II** and select the correct answers with the codes given below

List-I

- P. Yield point elongation
- Q. Spring back
- R. Wrinkling
- S. Residual stress

List-II

- 1. Distortion of dimension
- 2. Leuder's bands
- 3. Plastic deformation
- 4. Compressive stress

Codes:

	P	Q	R	S
(a)	3	4	2	1
(b)	4	3	1	2
(c)	2	3	4	1
(d)	2	1	4	3

22. Consider the following operations in forging a hexagonal bolt from a round bar stock whose diameter is equal to bolt diameter

- 1. flatterring
- 2. upsetting
- 3. swaging
- 4. cambering

The correct sequence of these operations is

- (a) 1, 2, 3, 4
- (b) 2, 3, 4, 1
- (c) 2, 1, 3, 4
- (d) 3, 2, 1, 4

23. In open die forging a disc of diameter 200 mm and height 60mm is compressed without any barreling effect the final diameter of disc is 400 mm the true strain is
- (a) 1.986 (b) 1.686
(c) 1.386 (d) 0.602

24. In forging operation fullering is done to
- (a) draw out the material
(c) upset the material

- (b) bend the material
(d) extrude the material

25. Consider the following steps involved in hammer forging a connecting rod from bar stock

1. blocking
3. finishing
5. edging

2. trimming
4. fullering

The correct sequence of these operations is

- (a) 1, 4, 3, 2 and 5
(c) 5, 4, 3, 2 and 1

- (b) 4, 5, 1, 3 and 2
(d) 5, 1, 4, 2 and 3

26. A forging method for reducing the diameter of the bar and in the process making it long is termed as

- (a) fullering
(c) upsetting

- (b) punching
(d) extruding

27. The process of removing the burs or flash from a forged component in drop forging is called

- (a) swaging
(c) trimming

- (b) perforating
(d) fettling

28. Match **List-I** (Types of forging) with **List-II** (operations) and select the correct answers with the codes given below

List-I

- A. A drop forging
B. Press forging
C. Upset forging
D. Roll forging

List-II

1. Metal is gripped in dies & Pressure is applied on heated end
2. Squeezing action
3. Metal is placed Between rollers & pushed
4. Repeated hammer blows

	A	B	C	D
(a)	4	1	2	3
(b)	3	2	1	4
(c)	4	2	1	3
(d)	3	1	2	4

29. The forging defect due to hindrance to smooth flow of metal in component called lap occurred because

- (a) the corner radius provided is too large
(b) the corner radius provided is too small
(c) draft is not provided
(d) the shrinkage allowance is inadequate

30. Consider the following statements

Assertions (A) : Forging dies are provided with a taper or draft angles on vertical surfaces

Reason (R) : It facilitates complete filling of die cavity and favorable grain growth

- (a) both A and R are individually true and R is correct explanation of A
(b) both A and R are individually true and R is not correct explanation of A
(c) A is true but R is false
(d) A is false R is true

31. Match **List-I** (Forging/technique) with **List-II** (Processes) and select the correct answers using the codes given below

List-I

- A. Smith Forging
- B. Drop Forging
- C. Press Forging
- D. Machine Forging

List-II

- 1. Materials only upset to get the desired Shape
- 2. Carried out manually the blank in open dies
- 3. done in close impression dies by Hammers in the blows
- 4. done in close impression dies by continuous squeezing process

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	4	3	2	1
(c)	2	1	4	3
(d)	4	1	2	3

32. Cold forging results in improved quality due to which of the following

- 1. better mechanical properties of the process
- 2. unbroken grain flow
- 3. smoother finishes
- 4. high pressure

select the correct answers using the codes given below

- (a) 1, 2 and 3
- (b) 1, 2 and 4
- (c) 2, 3 and 4
- (d) 1, 3 and 4

33. In wire drawing process, the bright shining surface on the wire is obtained if one:

- (a) ones not use a lubricant
- (b) low tooling cost
- (c) uses thick paste lubricant
- (d) use thin fluid lubricant

34. Which one of the following factors promotes the tendency for wrinkling in the process of drawing?

- (a) increase in the ratio of thickness to blank diameter of work material
- (b) decrease in the ratio of thickness to blank diameter of work material
- (c) decrease in the holding force on the blank
- (d) use of solid lubricants

35. Which one of the following lubricants is most suitable for drawing mild steel wires?

- (a) sodium stearate
- (b) water
- (c) lime-water
- (d) kerosene

36. In drawing operation if D_i = initial diameter and D_o = outgoing diameter, then what is the degree of drawing equal to?

(a) $\frac{D_i - D_o}{D_i}$

(b) $\frac{D_o - D_i}{D_o}$

(c) $\frac{D_i^2 - D_o^2}{D_i^2}$

(d) $\sqrt{\frac{D_i^2 - D_o^2}{D_i^2}}$

37. In a wire drawing operation, diameter of a steel wire is reduced from 10 mm to 8 mm. The mean flow of the material is 400 MPa. The ideal force required for drawing (ignoring friction and redundant work) is
- (a) 4.48 kN (b) 8.97 kN
(c) 20.11 kN (d) 31.41 kN
38. A cup of 10 cm height and 5 cm diameter is to be made from a sheet metal of 2 mm thickness. The number of deductions necessary will be (if the LDR of the material is 1.9):
- (a) one (b) two
(c) three (d) four

39. Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

- A. Drawing
B. Rolling
C. Wire drawing
D. Steel metal

List-II

1. Soap solution
2. Camber
3. Pilots
4. Crater operations
5. Ironing progressive dies

Codes:

	A	B	C	D
(a)	2	5	1	4
(b)	4	1	5	3
(c)	5	2	3	4
(d)	5	2	1	3

40. Consider the following statements: earing in a drawn cup can be due to non-uniform
1. speed of the press 2. clearance between tools
3. material properties 4. blank holding
- which of these statements are correct?
- (a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1, 2 and 4
41. A shell of 100 mm diameter and 100 mm height with the corner radius of 0.4 mm is to be produced by cup drawing. The required blank diameter is:
- (a) 118 mm (b) 161 mm
(c) 224 mm (d) 312 mm
42. Which of the following types of stresses is/are involved in the wire drawing operation?
- (a) Tensile only
(b) compressive only
(c) a combination of tensile and compressive stresses
(d) a combination of tensile, compressive and shear stresses
43. In the deep drawing of cups, blanks show a tendency to wrinkle up around the periphery (flange). The most likely cause and remedy of the phenomenon are, respectively
- (a) buckling due to circumferential compression; increase blank holder pressure
(b) high blank holder pressure and high friction; reduce blank holder pressure and apply lubricant
(c) high temperature causing increase in circumferential length; apply coolant to blank
(d) buckling due to circumferential compression; decrease blank holder pressure
44. A cylindrical vessel with flat bottom can be deep drawn by
- (a) shallow drawing (b) single action deep drawing
(c) double action deep drawing (d) triple action deep drawing

45. Which of the following methods can be used for manufacturing 2 meter long seamless metallic tubes?

- | | |
|------------|--------------|
| 1. drawing | 2. extrusion |
| 3. rolling | 4. spinning |

Which of the following statements are correct?

- | | |
|----------------|----------------|
| (a) 1 and 2 | (b) 2 and 3 |
| (c) 1, 3 and 4 | (d) 2, 3 and 4 |

46. Consider the following statements if forward extrusion process

1. The ram and the extruded product travel in the same direction
2. The ram and the extruded product travel in the opposite direction
3. The speed of travel of the extruded product is the same as that of the ram
4. The speed of the travel of the extruded product is greater than that of the ram

Which of the following statements are correct

- | | |
|-------------|-------------|
| (a) 1 and 3 | (b) 2 and 3 |
| (c) 1 and 4 | (d) 2 and 4 |

47. The following operations are performed while preparing the billets for extrusion process

- | | |
|----------------------|-----------------------------------|
| 1. Alkaline cleaning | 2. Phosphate coating |
| 3. Picking | 4. Lubricating with reactive soap |

the correct sequence of these operations is

- | | |
|----------------|----------------|
| (a) 3, 1, 4, 2 | (b) 1, 3, 2, 4 |
| (c) 1, 3, 4, 2 | (d) 3, 1, 2, 4 |

48. Which of the following statements are the salient features of hydrostatic extrusion?

1. It is suitable for soft and ductile material
2. It is suitable for high-strength super-alloys
3. The billet is inserted in to the extrusion chamber and pressure is applied by ram to extrude the billet through the die
4. The billet is inserted in to the extrusion chamber where it is surrounded by suitable liquid. The billet is extruded through the die by applying pressure to the liquid

Select the correct answer using the codes given below:

- | | |
|-------------|-------------|
| (a) 1 and 3 | (b) 1 and 4 |
| (c) 2 and 3 | (d) 2 and 4 |

49. A brass billet is to be extruded from its initial diameter of 100 mm to a final diameter of 50 mm. The working temperature of 700°C and the extrusion constant is 250 MPa. The force required for extrusion is

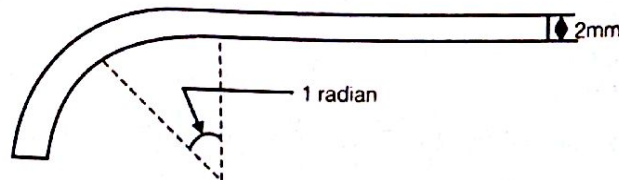
- | | |
|-------------|-------------|
| (a) 544 MN | (b) 2.72 MN |
| (c) 1.36 MN | (d) 0.36 MN |

50. Magnesium is extruded and not rolled because

- (a) It has a low melting point
- (b) It has low density
- (c) Its reactivity with roll material is high
- (d) It has a close-packed hexagonal structure

51. Which of the following materials is used in the manufacture of extrusion nozzles?
(a) Grey cast iron (b) Malleable cast iron
(c) White cast iron (d) Nodular cast iron
52. Extrusion force does not depend upon the
(a) extrusion ratio (b) type of extrusion process
(c) material of the die (d) working temperature
53. What does hydrostatic pressure in extrusion process improve
(a) ductility (b) type of extrusion process
(c) brittleness (d) tensile strength
54. Which of the following are the characteristics of extrusion process?
1. faster speed of production
2. good surface finish
3. dimensions can be maintained with close tolerances
4. mechanical properties of the extruded products are inferior to the that of the rolled products
Select the correct answer using the following codes given below:
(a) 1 and 2 (b) 1, 2 and 3
(c) 3 and 4 (d) 1 and 4
55. **Assertion(A)** : Indirect extrusion operation can be performed either by moving ram or by moving the container
Reason(R) : Advantage in indirect extrusion is less quantity of scarp compared to direct extrusion
(a) Both A and R are individually true and R is the correct explanation of the A
(b) both A and R are individually true but R is not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
56. Which of the following is the correct statements?
(a) Extrusion is used for the manufacture of seamless tubes
(b) Extrusion is used for reducing the diameter of round bars and tubes by rotating dies which open and close rapidly on the work
(c) Extrusion is used to improve fatigue resistance of the metal by setting up compressive stresses on its surface
(d) Extrusion comprises pressing the metal inside a chamber to force it out by high pressure through an orifice which is shaped to provide the desired form of the finished part
57. Which one the following processes necessarily mandrel of requisite diameter to form the internal hole?
(a) Hydrostatic extrusion (b) Tube drawing
(c) Swaging (d) Wire drawing
58. **Assertion (A)**: Greater force on the plunger is required in the case of the direct extrusion than indirect one
Reason (R): In case of direct extrusion, the direction of the force applied on the plunger and the direction of the movement of the extruded metal are the same
(a) both A and R are individually true and R is correct explanation of A
(b) both A and R are individually true but R is not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

59. The bending force required for V-bending, U-bending and edge bending will be in the ratio of:
 (a) 1 : 2 : 0.5 (b) 2 : 1 : 0.5
 (c) 1 : 2 : 1 (d) 1 : 1 : 1
60. What is the bend allowance in the following Fig. if the bend radius is 100 mm.



- (a) 99 mm (b) 100 mm
 (c) 101 mm (d) 102 mm
61. Which of the following is a continuous bending operation oils are used to produce long sections of formed shapes from coil or strip stock?
 (a) Strength forming (b) Roll forming
 (c) Roll bending (d) Spinning
62. Match the correct combination for the following metal working processes

Processes	Associated state of stress Tension
P. Blanking	1. Tension
Q. Stretch forming	2. Compression
R. Coining	3. Shear
S. Deep drawing	4. Tension and compression
	5. Tension and shear
(a) P-2,Q-1,R-3,S-4	(b) P-3,Q-4,R-1,S-5
(c) P-5,Q-3,R-3,S-1	(d) P-3,Q-1,R-2,S-4

63. **Assertion (A):** In sheet metal blanking operation, clearance must be given to die:

Reason (R): The blank should be of required dimensions

- (a) both A and R are individually true and R is correct explanation of A
 (b) both A and R are individually true but R is not the correct explanation of A
 (c) A is true but R is false
 (d) A is false but R is true
64. In the blanking operation to produce steel washer, the maximum punch load used is 2×10^5 N. The plate thickness is 4 mm and percentage penetration is 25%. The work done during this shearing operation is
 (a) 200 J (b) 400 J
 (c) 600 J (d) 800 J
65. The force requirement in a blanking operation of low carbon steel sheet is 5.0 kN. The thickness of the sheet is 't' and diameter of the blanked part is 'd'. For the same work material, if the diameter of the blanked part is increases 1.5 d and thickness reduced to 0.4 t, the new blanking force in kN is
 (a) 3.0 (b) 4.5
 (c) 290.7 (d) 8.0

66. Best position of crank for blanking operation in a mechanical press is:
 (a) top dead center (b) 20 degrees below top dead center
 (c) 20 degrees before bottom dead center (d) bottom dead center
67. Which of the following statements are correct for deep drawing.
 (a) Clearance at the corners of the punch is poor
 (b) The finish at the corners of the punch is poor
 (c) The finish at the corners of the die is poor
 (d) The punch and die alignment is not proper
68. Match **List-I** (Press-part) with **List-II** (Function) and select the correct answer using the following codes given below

List-I

- A. Punch plate
 B. Stripper
 C. Stopper
 D. Knock out

List-II

1. Assisting withdrawal of punch
 2. Advancing the work-piece through correct distance
 3. Ejection of the work piece from die cavity
 4. holding the small punch in the proper position

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	2	1	4	3
(c)	4	1	2	3
(d)	2	3	4	1

69. Consider the following statements related to piercing and blanking
 1. Shear on the punch reduces the maximum cutting force
 2. Shear increases the capacity of the press needed
 3. Shear increases the life of punch
 4. The total energy needed to make the cut remains unaltered due to provision of shear
 which of the following above statements are correct ?
 (a) 1 and 3 (b) 1 and 4
 (c) 2 and 3 (d) 3 and 4
70. A metal disc of 20mm diameter is to be punched from a sheet of 2 mm thickness. The punch and the dia clearance is 3%. The required punch dia meter is
 (a) 19.88 mm (b) 19.84 mm
 (c) 20.06 mm (d) 20.12 mm
71. What is the process of removing metal by a milling cutter which is rotated against the direction of travel of the work piece, called?
 (a) down milling (b) up milling
 (c) end milling (d) face milling
72. In deciding the clearance between the punch and die in press work in shearing, the following rule is helpful
 (a) punch size controls the hole size die size controls blank size
 (b) punch size controls both hole size and blank size
 (c) die size controls both hole size and blank size
 (d) die size controls hole size and punch size controls blank size
73. Which is the force required to be exerted by the punch in order to shear out the blank (from a circular disk) of 20 mm diameter and 1.5 mm thickness and having a shear strength equal to 300 MPa?

- (a) 9.0 kN
(c) 28.3 kN

- (b) 18.0 kN
(d) 45.0 kN

74. Steel balls are manufactured by

- (a) casting
(b) machining
(c) cold heading
(d) sintering

75. Match **List-I** (Metal forming process) with **List-II** (Associated feature) and select the correct answer using the following codes given below the lists:

List-I

- A. Blanking
B. Flow forming
C. Roll forming
D. Embossing

List-II

1. Shear angle
2. Coiled stock
3. Mandrel
4. Closed matching dies

Codes:

	A	B	C	D
(a)	1	3	4	2
(b)	3	1	4	2
(c)	1	3	2	4
(d)	3	1	2	2

76. Match **List-I** (Parts) with **List-II** (Manufacturing processes) and select the correct answer using the codes given below the lists:

List-I

- A. Seamless tubes
B. Accurate and forming and smooth tubes
C. Surfaces having peen in higher hardness
D. Embossing

List-II

1. Roll
2. Shot
3. Forging & fatigue strength
4. Cold forming

Codes:

	A	B	C	D
(a)	1	4	2	3
(b)	2	3	1	4
(c)	1	3	2	4
(d)	2	4	1	3

77. The collapsible tooth paste tubes are manufactured

- (a) direct extrusion
(b) piercing
(c) impact extrusion
(d) indirect extrusion

78. Match **List-I** (Type of modeling) with **List-II** (Mechanism involve (d) and select the correct answer using the codes given below the lists:

List-I

- A. Compression moulding
B. Injected moulding
C. Jet moulding
D. Extrusion moulding

List-II

1. Mould cavity must be heated to curve the plastic forced in to
2. Similar to hydraulic extrusion
3. Analogous to hot-pressing of powdered metals
4. Analogous to die casting of metals

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	4	3
(d)	3	4	1	2

79. Magnetic forming is an example of:
(a) cold forming (b) hot forming
(c) high energy rate forming (d) roll forming forming
80. Consider the following statements
1. Metal forming decreases harmful effects of impurities and improves mechanical strength
2. Metal working process is a plastic deformation process
3. Very intricate shapes can be produced by forging process as compared to casting process
Which of the statements given below are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only
81. Which is incorrect statement about results of cold working
(a) it increases corrosion resistance
(b) it increases strength, elasticity and hardness with a corresponding decrease in ductility
(c) handling of parts is easier
(d) dimensions tolerances and finish are high
82. In the metal forming processes, the stresses encountered are
(a) less than the yield strength of the material
(b) less than the fracture strength of the material and greater than yield strength
(c) less than the limit of proportionality
(d) less than the elastic limit
83. Rotary swaging is used for
(a) manufacturing bolts and rivets
(b) manufacturing seamless tubes
(c) improving fatigue resistance
(d) reducing diameter of round bars and tubes by rotating die which open and close rapidly on the work
84. Which is incorrect statement about results of hot working
(a) power requirements are low (b) surface finish is good
(c) grain refinement is possible (d) porosity in the metal is largely eliminated
85. Which of the following materials can't be forged
(a) wrought iron (b) cast iron
(c) mild steel (d) high carbon steel
86. Swaging
(a) causes a steadily applied pressure instead of impact force
(b) is used to force the end of a heated bar into a desired shape
(c) is a forging operation in which two halves of a rotating die open and close rapidly while impacting the end of the heated tube or shell
(d) is forging method for reducing the diameter of a bar and in the process making it longer
87. The increase in hardness due to cold working is called
(a) cold hardening (b) hot hardening
(c) work hardening (d) age-hardening
88. The operation of removing the burr or flash from the forged parts in drop forging is known as
(a) lancing (b) trimming
(c) coining (d) burring

89. Metallic cans are usually mass produced by the following process
 - (a) embossing
 - (b) coining
 - (c) spinning
 - (d) deep drawing
90. Spinning operation is carried out on
 - (a) hydraulic press
 - (b) mechanical press
 - (c) lathe
 - (d) milling machine
91. Production of contours in flat blanks is termed as
 - (a) blanking
 - (b) rubbing
 - (c) perforating
 - (d) punching
92. Thread rolling is some what like
 - (a) cold extrusion
 - (b) cold rolling
 - (c) cold forging
 - (d) plug rolling
93. Upset forging
 - (a) causes a steadily applied pressure instead of impact force
 - (b) is used to force the end of a heated bar into a desired shape
 - (c) is a forging operation in which two halves of rotating die open and close rapidly while impacting the end of the heated tube or shell
 - (d) is a forging method for reducing the diameter of a bar and in the process making it longer
94. Which of the following process is different from the rest of the processes
 - (a) shot peening
 - (b) cold extrusion
 - (c) sand blasting
 - (d) drop forging
95. It is required to reduce a slab directly to strip in one pass. Which of the following rolling mills can do this function?
 - (a) three high mill
 - (b) four high mill
 - (c) planetary mill
 - (d) continuous rolling mill
96. In four high rolling mill the bigger rollers are called
 - (a) guide rolls
 - (b) back up rolls
 - (c) main rolls
 - (d) support rolls
97. Notching is the operation of
 - (a) removal of excess metal from the edge of a strip to make it suitable for drawing without wrinkling
 - (b) cutting of the excess metal at edge which was required for gripping purpose during press working operation.
 - (c) cutting in a single line across a part of the metal strip to allow bending or forming in progressive die operation while the part remains attached to the strip.
 - (d) punching in which punch is stopped as soon as the metal fracture is complete and metal is not removed but held in hole
98. Lancing is the operation of
 - (a) removal of excess metal from the edge of a strip to make it suitable for drawing without wrinkling
 - (b) cutting of the excess metal at edge which was required for gripping purpose during press working operation
 - (c) cutting in a single line across a part of the metal strip to allow bending or forming in progressive die operation while the part remains attached to the strip
 - (d) punching in which punch is stopped as soon as the metal fracture is complete and metal is not removed but held in hold.

99. Flange wrinkling is the defect found in
 (a) blanking (b) spinning
 (c) bending (d) deep drawing
100. Injection moulding is the ideal method of processing
 (a) plastics (b) thermo-setting plastics
 (c) thermoplastics (d) non-ferrous materials
101. The ductility of a material with work hardening
 (a) increases
 (b) decreases
 (c) remains unaffected
 (d) may increase/decrease depending on its tensile strength
102. Blanking and piercing operation can be performed simultaneously in
 (a) simple die (b) progressive die
 (c) compound die (d) combination die
103. In progressive dies
 (a) two or more cutting operations can be performed simultaneously
 (b) cutting and formation operations are combined and carried out in single operations
 (c) workpiece moves from one station to other with separate operation performed at each station
 (d) all of the above

OOOO

ANSWERS

METAL FORMING

1. (b)	2. (b)	3. (a)	4. (c)	5. (b)	6. (a)	7. (a)
8. (b)	9. (d)	10. (b)	11. (d)	12. (b)	13. (d)	14. (c)
15. (c)	16. (d)	17. (c)	18. (a)	19. (d)	20. (a)	21. (a)
22. (a)	23. (c)	24. (a)	25. (b)	26. (a)	27. (c)	28. (c)
29. (b)	30. (c)	31. (a)	32. (a)	33. (d)	34. (c)	35. (a)
36. (c)	37. (b)	38. (b)	39. (d)	40. (b)	41. (c)	42. (a)
43. (a)	44. (d)	45. (a)	46. (c)	47. (a)	48. (d)	49. (b)
50. (c)	51. (c)	52. (c)	53. (a)	54. (d)	55. (c)	56. (d)
57. (b)	58. (b)	59. (a)	60. (c)	61. (b)	62. (d)	63. (d)
64. (a)	65. (a)	66. (b)	67. (b)	68. (a)	69. (a)	70. (a)
71. (b)	72. (a)	73. (c)	74. (c)	75. (c)	76. (a)	77. (c)
78. (b)	79. (c)	80. (a)	81. (a)	82. (b)	83. (d)	84. (b)
85. (b)	86. (c)	87. (c)	88. (b)	89. (d)	90. (c)	91. (a)
92. (b)	93. (b)	94. (c)	95. (c)	96. (b)	97. (a)	98. (c)
99. (d)	100. (b)	101. (b)	102. (c)	103. (c)		

Welding

Welding is the process of joining similar or dissimilar metals with or without the application of heat and pressure. Weldability of a material depends upon various factors like the metallurgical changes that occur due to welding, changes in hardness in and around the weld, extent of oxidation and the extent of cracking tendency of the joint.

6.1 METALLURGY IN WELDING

Metal is heated over a range of temperature up to fusion and followed by cooling to ambient temperature. Because of differential heating, the material far away from the weld bead will be simply warmed out but as the weld area is approached, progressively higher temperatures are obtained, resulting in a corresponding complex microstructure. The heating and cooling also results in setting up internal stresses and plastic strain in the weld. So at high temperatures physical, chemical and metallurgical properties are liable to change.

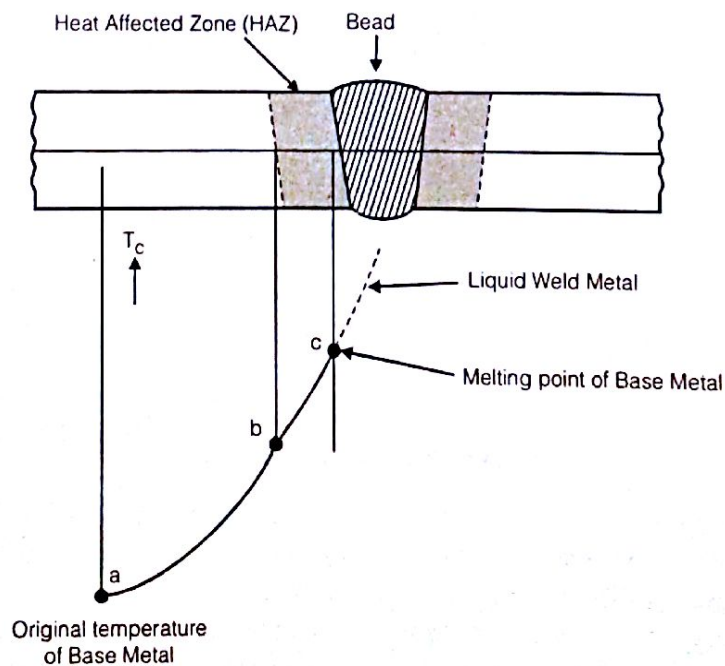


Fig. 6.1 : Graph showing the change of thermal conditions

Depending on the welding process used and the metal being welded, there exists wide variation in the maximum liquid temperature and in the slope of temperature gradient curve for the unfused metal. Three distinct zones can be identified in a weld joint which are :

1. Base metal
2. Heat affected zone.
3. Weld metal.

A joint produced without the filler metal is called autogenous and its weld zone is composed of the resolidified base metal. A joint made with a filler metal called weld metal. After the application of heat and the introduction of the filler metal into the weld area, the molten weld joint is allowed to cool to ambient temperatures. Since central portion of the bead will be cooled slowly, long columnar grains will develop (see TTT diagram discussion in chapter 2) and in the outward direction grains will become finer and finer (Fig. 6.2). So the ductility and toughness of bead metal at the centre will be higher. Thus the original structure consisting of ferrite and pearlite in steels is changed to another micro structure. The composition of the first crystals which form in a molten alloy may be quite different from the composition of liquid but as the freezing proceeds, the crystals readjust their composition to that of the initial liquid alloy in order to satisfy the condition of equilibrium depending upon the type of phase diagram exhibit by alloy.

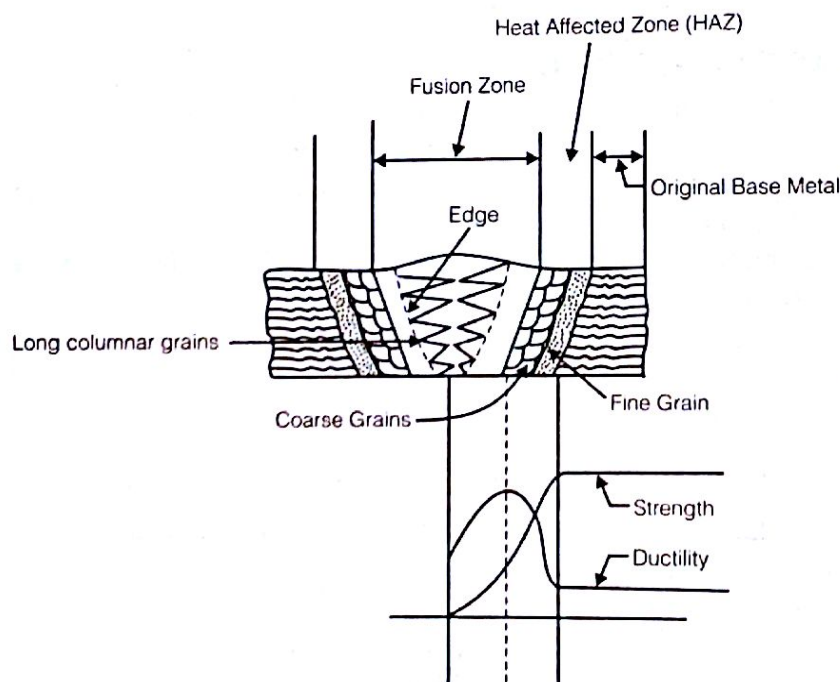


Fig. 6.2 : Regions in weld bead

The weld metal when it is in the molten state has a good capacity to dissolve gases which come into contact with it like oxygen, nitrogen and hydrogen. As the metal starts cooling, capacity of dissolving gases goes on decreasing, thus causing additional volume of gases to be evolved. Due to the appearance of mushy zone during solidification, a portion of these gases may be trapped into the bead called porosity. This decreases the strength of weldment.

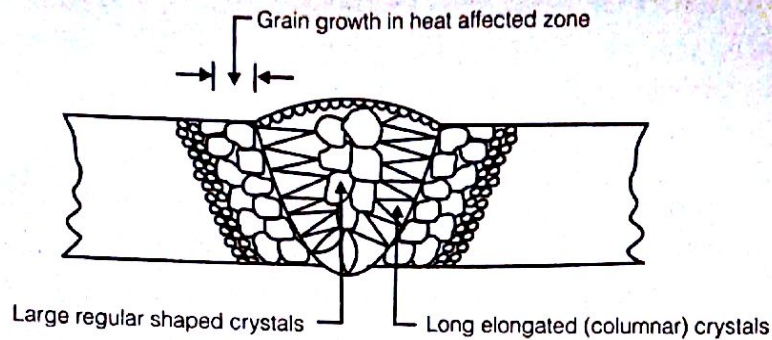


Fig. 6.3 : Structure of the weld metal

As shown in Fig. 6.3 in the structure of weld section the columnar crystals are formed near fusion faces due to directional cooling of weld towards the centre. Since the inner part of the weld cools more uniformly it results an enlarged but regular crystal structure. Surface of weld beyond the slag coating is being cooled very fast, so small and slightly chilled crystal structure will be formed. Cooling rates can be controlled by preheating of the weld before welding.

The heat affected zone is within the base metal itself. It has a microstructure different from that of the base metal prior to welding, because it is subjected to elevated temperature for a substantial period of time during the welding. The portions of the base metal that are far from the heat source do not undergo any structural changes during the welding. The heat applied during welding recrystallizes the elongated grains of the base metal, grains that are away from the weld metal will recrystallizes into fine equiaxed grains.

6.2 BEAD GEOMETRY

By the application of heat source we are depositing the liquid metal at the joint. The depth, up to which the material is liquified is called penetration and there will be raised portion of the plane of parent metal called reinforcement. In ideal cases the dilution should be as close to be as 100%.

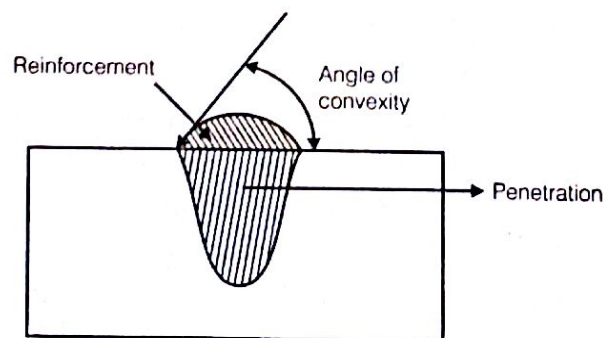


Fig. 6.4 : Bead geometry

A_p = Area of penetration

A_R = Area of Reinforcement

$$\text{Dilution} = \frac{A_p}{A_p + A_R}$$

6.3 CLASSIFICATION OF WELDING PROCESS

1. Arc Welding
2. Resistance Welding
3. Solid State Welding
4. Radiant Energy Welding
5. Thermit Welding
6. Allied process
7. Gas Welding

6.4 ARC WELDING

6.4.1 Shielded Metal Arc Welding (SMAW)

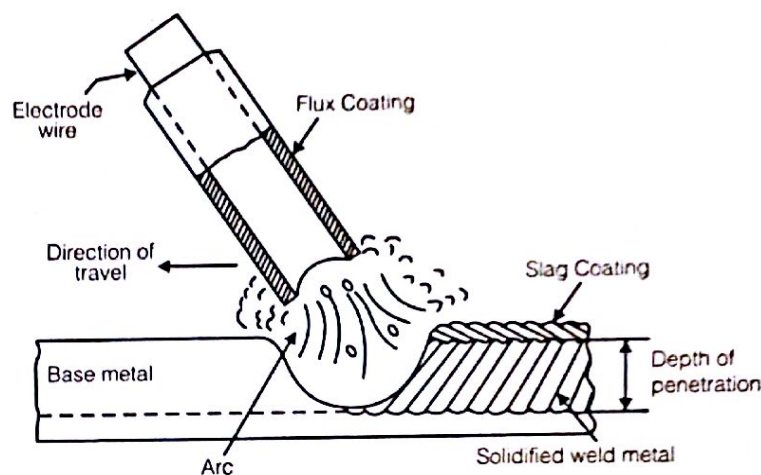


Fig. 6.5 : Welding using SMAW process

This is also called as stick electrode welding or coated electrode welding or manual arc welding. It uses coated electrodes of 2.5 to 6.35 mm diameter and 300 to 450 mm length held in an electrode holder. The power source used is of constant current type. Initially the arc is being created between wire electrode and work piece. Flux by taking energy from the arc gets melted and a mixture of liquid metal and molten flux gets simultaneously settled in the groove. Since the density of flux is lower, it comes over the surface of bead and provides slag coating. It has following functions.

- (a) Since flux gives alloys to the bead material, bead becomes stronger than even the parent metal. The region in the parent metal near the bead where the temperature has gone beyond the recrystallization temperature is called heat affected zone and it is the weakest portion in the weld metal.
- (b) It provides the heat treatment to the bead and as a result of that at the center of the bead there will be coarse grains and in the outward direction grains become finer and finer.
- (c) It protects the bead from the attack of atmosphere gases.

There are two movements of electrode holder.

(a) The rate at which electrode wire is getting consumed with the same rate the electrode has to be fed towards the molten pool. It is because arc length decides the arc voltage and arc current. If lower is the current settings, the temperature of the molten pool will be lower, as a result of that the liquid flux (slag) trying to come out of material will be solidified and slag will be trapped with in the bead. This defect is called slag inclusion. Also variable current leads to improper bead geometry.

(b) Movement of electrode along the longitudinal direction of bead.

If both these movements are controlled manually it is called manual arc welding. If first movement is controlled by machine it is called **semi-automatic arc welding** and if both movements are controlled by machine it is called **automatic arc welding**. The temperature in the core of the arc ranges between $6000 - 7000^{\circ}\text{C}$. SMAW can be performed both on AC and DC source with drooping characteristics.

6.4.2 Transformer

Constant current type transformer : In manual arc welding since arc length can not be controlled, so arc current is controlled by the transformer. A conventional arc welding power source is known as the constant current machine. It has the drooping volt – ampere characteristic curve as shown in Fig. 6.6

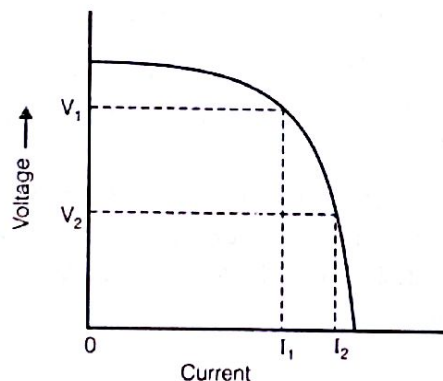


Fig. 6.6 : Characteristics of constant current type transformer

The constant current curve shows that the welding power source produces maximum output voltage with no load and as load increases, the output voltage decreases. As it can be observed in Fig 6.6 that for a major change in arc voltage, there is insignificant change in arc current.

Constant voltage transformer : A constant voltage welding power source has essentially a flat volt ampere characteristics curve though usually with a slight droop. The curve may be shifted up or down to change the voltage. These characteristics are used only for continuous electrode wire welding such as gas welding semiautomatic and automatic welding processes.

If the load in the circuit changes, the power source automatically adjusts its current output to satisfy the requirement and maintains essentially the same voltage across the output terminals. The constant voltage welding power system has its greatest advantage when the current density of the electrode wire is high.

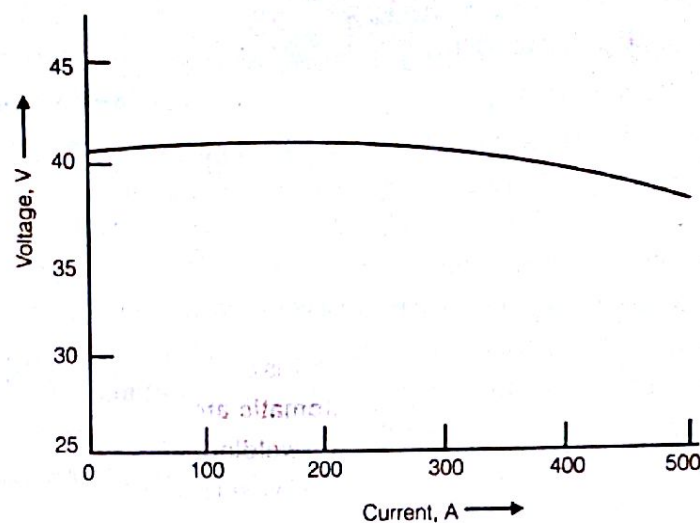


Fig. 6.7 : Characteristics of constant voltage transformer

$$V = (OCV) - \left[\frac{OCV}{SCC} \right] I$$

This is for semi automatic arc welding.

OCV = Open circuit voltage.

SCC = Short circuit current.

For stable arc in constant voltage transformer $V_{arc} = V_{transformer}$

For stable arc in constant current transformer $I_{arc} = I_{transformer}$

Example : 6.1

The arc length voltage characteristic is given by expression $V = 24 + 4l$ (l = arc length in mm). The volt ampère characteristic of a power source can be approximated by a straight line with open circuit voltage 80V and short circuit current is 600A. Determine optimum arc length for maximum power.

Solution :

$$OCV = 80V$$

$$SCC = 600A$$

$$V = 80 - \left[\frac{80}{600} \right] I$$

Stable

$$V_t = V_a$$

$$I = F(l)$$

$$24 + 4l = 80 - \left[\frac{80}{600} \right] I$$

$$\left[\frac{80}{600} \right] I = 80 - 24 - 4l$$

$$I = [56 - 4l] \left[\frac{60}{8} \right]$$

$$P = VI$$

$$\begin{aligned}
 P &= [56 - 4I] \left(\frac{60}{8} \right) [24 + 4I] \\
 &= \left[\frac{60}{8} \right] [(56 - 4I)(24 + 4I)] \\
 P &= \left[\frac{60}{8} \right] [(56)(24) + 128I - 16I^2]
 \end{aligned}$$

For maximum power $\frac{dp}{dI} = 0$

$$128 - 32I = 0$$

$$I = 4 \text{ mm}$$

The arc length for maximum power is 4 mm.

Example : 6.2

Volt-amp characteristics of a power source is given by equation $I_t^2 = -600(V - 60)$

1. If the arc characteristic is $I = 20(V - 16)$, determine the power of stable arc.
2. If arc length voltage are represented by $V_a = 30 + 5.5I$, determine optimum arc length for maximum power.

Solution :

1. Arc characteristics is given by

$$I_a = 20(V - 16)$$

Volt-amp characteristics of power source is given by

$$I_t^2 = -600(V - 60),$$

as current-voltage variation is parabolic, so the power source is dropper or constant current source.

Hence, for the stability of arc;

$$I_t = I_a;$$

(i.e. current across transformer is equal to current across arc)

or

$$I_t^2 = I_a^2$$

$$-600(V - 60) = (20(V - 16))^2$$

$$-600V + 36,000 = 400V^2 + 102,400 - 12,800V$$

$$400V^2 - 12,200V + 66,400 = 0$$

$$4V^2 - 122V + 664 = 0$$

Solve this equation, we get roots of this equation as

$$V = \frac{122 \pm \sqrt{122^2 - 4 \times 4 \times 664}}{2 \times 4} = \frac{122 \pm 65.26}{8}$$

$\Rightarrow$

$$V = 23.40 \text{ volts, } 7.09 \text{ volts}$$

But at

$$V = 7.09 \text{ volts; } I_a = 20(V - 16)$$

$$= 20(7.09 - 16) = -ve$$

So neglect

$$V = 7.09 \text{ volts}$$

Hence voltage (v) = 23.40 volts

Current of arc at this voltage = $I = 20 (v - 16)$

$$\Rightarrow I = 20 (23.40 - 16) = 148 \text{ Amps.}$$

So, power of arc = $V \times I$

$$= 23.40 \times 148 = 3463.2 \text{ W}$$

or Power = 3.463 kW Ans.

2. Arc length voltage is given by

$$V = 30 + 5.5l$$

Volt-amp characteristic of power source is given by

$$I_t^2 = -600 (V - 60);$$

On putting value of V in the above equation, we get;

$$I_t^2 = -600 (30 + 5.5l - 60)$$

$$I_t^2 = -600 (5.5l - 30)$$

$$I_t = \{-600 (5.5l - 30)\}^{1/2}$$

As, power (P) is given by

$$P = V \times I$$

$$P = (30 + 5.5l) \times \{-600 (5.5l - 30)\}^{1/2}$$

For maximum power, $\frac{dp}{dl} = 0$

$$\frac{dp}{dl} = \left\{ (30 + 5.5l) \times \frac{1}{2} \{-600 (5.5l - 30)\}^{-1/2} \times (-600 \times 5.5) \right\} + \left\{ -600 (5.5l - 30)^{1/2} \right\} \times 5.5$$

$$\text{equate } \frac{dp}{dl} = 0$$

$$\Rightarrow \frac{(30 + 5.5l) \{-600 (5.5l - 30)\}^{-1/2} (-600 \times 5.5)}{2} = \{-600 (5.5l - 30)\}^{1/2} \times 5.5$$

$$\Rightarrow \frac{(30 + 5.5l) \times (-600 \times 5.5)}{2} = -600 (5.5l - 30) \times 5.5$$

$$\Rightarrow \frac{(30 + 5.5l)}{2} = (5.5l - 30)$$

$$\Rightarrow 30 + 5.5l = 11l - 60$$

$$\Rightarrow 90 = 5.5l$$

$$\Rightarrow l = 16.36 \text{ mm}$$

Hence, optimum arc length for maximum power = $I_{\text{opt}} = 16.36 \text{ mm}$

Example : 6.3

Arc length voltage characteristics can be represented by

$$V = 20 + 4l$$

If the arc length in the welding operation varies between 4mm to 6mm and the welding current between 450 Amp. to 550 Amp, assuming a linear power source characteristic, calculate.

1. Open circuit voltage (OCV)
2. Short circuit current (SCC)

Solution :

Power source characteristic is linear. (given)

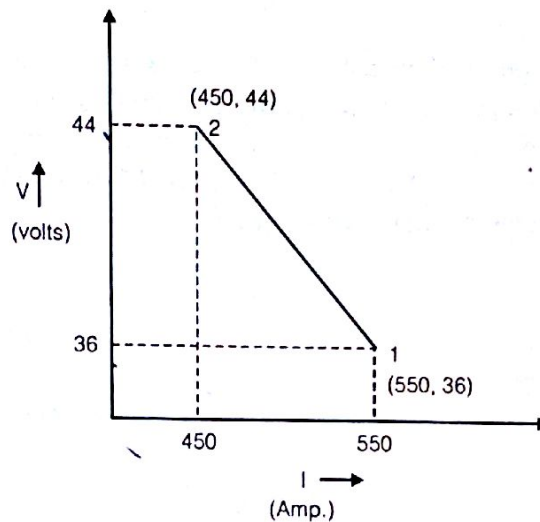


Fig. 6.8

as arc length voltage characteristic is;

$$V = 20 + 4l$$

at arc length (l_1) = 4 mm

$$V_1 = 20 + (4 \times 4) = 36 \text{ volts}$$

at arc length (l_2) = 6 mm

$$V_2 = 20 + (4 \times 6) = 44 \text{ volts}$$

equation of line can be written as;

$$(V - V_1) = \left(\frac{V_2 - V_1}{I_2 - I_1} \right) (I - I_1)$$

$$(V - 36) = \left(\frac{44 - 36}{450 - 550} \right) (I - 550)$$

$$V - 36 = \frac{-8}{100} (I - 550)$$

$\Rightarrow$

$$V - 36 = \frac{-8}{100} I + 44$$

$\Rightarrow$

$$V = 80 - \left(\frac{8}{100} \right) I \quad \dots(1)$$

as linear power source characteristic is given by

$$V = OCV - \left(\frac{OCV}{SCC} \right) I \quad \dots(2)$$

Compare (1) and (2); we get

$$OCV = 80V$$

$$\frac{OCV}{SCC} = \frac{8}{100} \Rightarrow SCC = 1000 \text{ Amp.}$$

$\Rightarrow$

$$OCV = 80 \text{ volts}$$

$$SCC = 1000 \text{ Amp.}$$

Example : 6.4

A direct current welding machine with a linear power source characteristic provides open circuit voltage of 80 V and short circuit current of 800 A. During welding with the machine, the measured arc current is 500 A corresponding to an arc length of 5.0 mm and the measured arc current is 460 A corresponding to an arc length of 7.0 mm. What is the linear voltage (E) - arc length (L) characteristic of the welding arc.

Solution :

Power source characteristic is linear.

Open circuit voltage (OCV) = 80V

Short circuit current (SCC) = 800A

For the linear power source characteristics, voltage (E) is given by:

$$E = OCV - \left(\frac{OCV}{SCC} \right) I$$

$\Rightarrow$

$$E = 80 - \frac{80}{800} \times I$$

$$E = 80 - \left(\frac{1}{10} \right) I \quad \dots(1)$$

Let linear voltage (E) - arc length (l) characteristic of welding arc be

$$E = a + b/l \quad \dots(2)$$

a, b are constants

For arc current (I) = 500 A, arc length (l) = 5 mm;

From (1)

$$E = 80 - \frac{1}{10} \times 500$$

From (2)

$$E = 80 - 50 = 30V$$

$$E = a + 5b$$

Equate these values of E, we get

$$a + 5b = 30 \quad \dots(3)$$

Similarly

For arc current (I) = 460 A,
arc length (l) = 7 mm

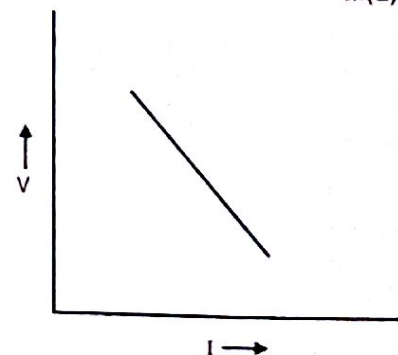


Fig. 6.9

From (1) $E = 80 - \frac{1}{10} \times 460$

$$E = 34V$$

From (2) $E = a + 7b$

Equate these values of E, we get

$$a + 7b = 34 \quad \dots(4)$$

On solving equation (3) and (4)

$$a + 5b = 30 \quad \dots(3)$$

$$a + 7b = 34 \quad \dots(4)$$

Subtract equation (3) from (4); we get

$$2b = 4 \Rightarrow b = 2$$

Put this value of $b = 2$ in equation (3)

$$a + (5 \times 2) = 30$$

$$\Rightarrow a = 20$$

So, equation (2) becomes

$$E = 20 + 2I$$

Example : 6.5

In arc welding of a butt joint, the welding speed is to be selected such that highest cooling rate is achieved. Melting efficiency and heat transfer efficiency are 0.5 and 0.7, respectively. The area of the weld cross section is 5 mm^2 and the unit energy required to melt the metal is 10 J/mm^3 . If the welding power is 2 kW . What is the welding speed in mm/s .

Solution :

Given,

$$\text{Area of weld cross-section (A)} = 5 \text{ mm}^2$$

$$\text{Unit energy required to melt the metal} = 10 \text{ J/mm}^3$$

$$\text{Welding power} = 2 \text{ kW} = 2000 \text{ W}$$

$$\text{Melting efficiency } (\eta_m) = 0.5$$

$$\text{Heat transfer efficiency } (\eta_H) = 0.7$$

$$\text{Let welding speed} = V \text{ mm/s}$$

$$\text{So, Volume welded per second} = (\text{Area of cross-section of weld}) \times (\text{Welding speed})$$

$$\text{Volume per second} = 5 \times V = 5V \text{ mm}^3/\text{s}$$

$$\text{as unit energy required to melt the metal} = 10 \text{ J/mm}^3$$

$$\begin{aligned} \text{So, total energy required to melt the metal} &= 10 \times \text{volume} \\ &= 10 \times 5V \text{ J/s} \end{aligned}$$

$$\text{Total energy required to melt the metal} = 50V \text{ J/s}$$

as melting efficiency $(\eta_m) = 0.5$, so the total energy supplied to melt the metal

$$= H_m = \left(\frac{50V}{0.5} \right) \frac{\text{J}}{\text{s}} \quad \dots(1)$$

$$\text{as welding power} = 2000 \text{ W}$$

$$\text{and heat transfer efficiency } (\eta_H) = 0.7$$

$$\text{So, total energy available } H_T = \eta_H \times 2000 = 2000 \times 0.7 \text{ W}$$

$$H_T = 1400 \text{ W} \quad \dots(2)$$

as (1) and (2) are same, so equate these,

$$\frac{50V}{0.5} = 1400$$

⇒

$$V = 14 \text{ mm/s i.e. welding speed} = 14 \text{ mm/s}$$

Example : 6.6

Calculate the melting efficiency in case of arc welding of steel with a potential of 20 V and current of 200 A. The travel speed is 5 mm/s and the cross-sectional area of the joint is 20 mm². Heat required to melt steel may be taken as 10 J/mm³ and the heat transfer efficiency as 0.85.

Solution :

Given,

$$\text{Potential (V)} = 20 \text{ volts}$$

$$\text{Current (I)} = 200 \text{ Amp.}$$

$$\text{Weld speed (v)} = 5 \text{ mm/s}$$

$$\text{Cross-section area of joint (A)} = 20 \text{ mm}^2$$

$$\text{Heat required to melt steel} = 10 \text{ J/mm}^3$$

$$\text{Heat transfer efficiency } (\eta_T) = 0.85$$

$$\text{Let Melting efficiency} = \eta_m$$

as power is given by

$$P = V \times I$$

$$\Rightarrow P = 20 \times 200 = 4000 \text{ W}$$

$$\text{as heat transfer efficiency } (\eta_T) = 0.85$$

$$\begin{aligned} \text{So, total energy available at bead} &= P \times \eta_T \\ &= 4000 \times 0.85 \\ &= 3400 \text{ W} \end{aligned}$$

...(1)

Volume welded per second is given as,

$$\begin{aligned} \text{Volume welded per second} &= (\text{cross-section area of weld}) \times (\text{weld speed}) \\ &= 20 \times 5 = 100 \text{ mm}^3/\text{s} \end{aligned}$$

$$\text{as, heat required to melt steel} = 10 \text{ J/mm}^3$$

$$\text{So, total heat required to melt steel} = 10 \times 100 = 1000 \text{ J/s}$$

$$\text{as melting efficiency} = \eta_m$$

$$\text{So total heat to be supplied to melt steel} = \frac{1000}{\eta_m} \quad \dots(2)$$

as (1) and (2) are same,

$$\text{so} \quad 3400 = \frac{1000}{\eta_m}$$

$$\Rightarrow \eta_m = 0.2941$$

$$\text{i.e. Melting efficiency} = 29.41\%$$

Example : 6.7

The cross-section of weld bead is shown in Fig. 6.10. The profile of the bead and the fusion zone are taken circular for convenience. Bead width and radii of curvature of circular profiles are given in the figure. Calculate

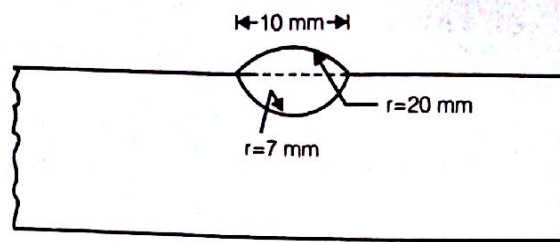


Fig. 6.10

- (a) the bead height,
(b) penetration, and
(c) dilution (%)

All dimensions in Fig. are in mm.

Solution :

As reinforcement is a part of circle of radius 20 mm.

As we know, perpendicular drawn from the centre on the chord bisect the chord as from the properties of circle we know

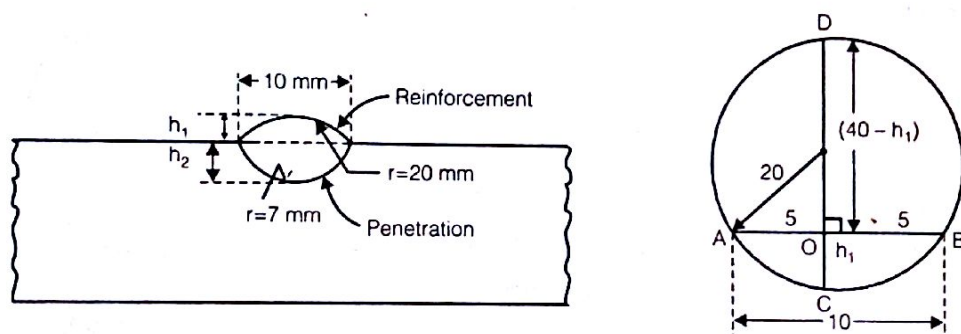


Fig. 6.11

$$OA \times OB = OC \times OD$$

$$5 \times 5 = h_1 \times (40 - h_1)$$

$$\Rightarrow h_1^2 - 40h_1 + 25 = 0$$

Roots of this equation are

$$\Rightarrow h_1 = \frac{40 \pm \sqrt{40^2 - 4 \times 25}}{2}$$

$$h_1 = \frac{40 \pm 38.72}{2}$$

$$h_1 = 39.36 \text{ mm}, 0.64 \text{ mm}$$

$$\Rightarrow h_1 = 0.64 \text{ mm}$$

Similarly, penetration is also a part of the circle of radius 7 mm.

From the properties of circle,

$$PT \times TQ = TS \times RT$$

$$5 \times 5 = h_2 \times (14 - h_2)$$

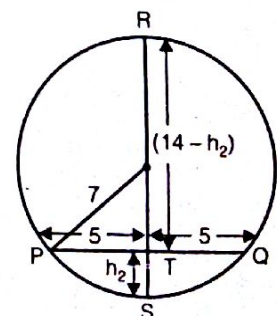


Fig. 6.12

$$\Rightarrow h_2^2 - 14h_2 + 25 = 0$$

So, roots of this equation are

$$h_2 = \frac{14 \pm \sqrt{14^2 - 100}}{2}$$

$$= \frac{14 \pm 9.79}{2}$$

$$h_2 = 11.89 \text{ mm}, 2.10 \text{ mm}$$

$$\Rightarrow h_2 = 2.10 \text{ mm}$$

$$(a) \text{ Bead height} = h_1 + h_2 = 0.64 + 2.10 = 2.74 \text{ mm Ans.}$$

$$(b) \text{ Penetration} = h_2 = 2.10 \text{ mm Ans.}$$

$$(c) \% \text{ dilution} = \left(\frac{A_p}{A_p + A_R} \right) \times 100$$

A_p = Penetration area

A_R = Reinforcement area

As penetration is a part of circle of radius 7 mm.

From $\triangle OBC$;

$$\sin \frac{\theta}{2} = \frac{BC}{OB} = \frac{5}{7}$$

$$\Rightarrow \frac{\theta}{2} = \sin^{-1} \left(\frac{5}{7} \right)$$

$$\Rightarrow \theta = 91.16^\circ$$

$$\text{So, area of sector} = \frac{\theta}{360^\circ} \times \pi r^2$$

$$= \frac{91.16}{360} \times \pi \times 7^2 = 38.98 \text{ mm}^2$$

area of $\triangle OAB$;

$$= \frac{1}{2} \times AB \times OC$$

$$= \frac{1}{2} \times 10 \times 4.9 \quad \{OC = OD - DC = 7 - 2.1 = 4.9 \text{ mm}\}$$

$$= 24.5 \text{ mm}^2$$

So, penetration area = Area of sector (OADB) - Area of $\triangle OAB$

$$A_p = 38.98 - 24.5 = 14.48 \text{ mm}^2$$

$$A_p = 14.48 \text{ mm}^2$$

Similarly

Reinforcement is a part of circle of radius 20 mm.

From $\triangle PST$;

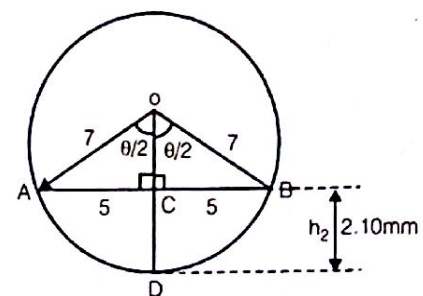


Fig. 6.13

$$\sin \frac{\theta}{2} = \frac{ST}{PS} = \frac{5}{20}$$

$$\Rightarrow \frac{\theta}{2} = \sin^{-1} \left(\frac{5}{20} \right)$$

$$\theta = 28.95^\circ$$

$$\text{So, area of sector (PQRS)} = \frac{\theta}{360^\circ} \times \pi r^2$$

$$= \frac{28.95}{360^\circ} \times \pi \times 20^2$$

$$= 101.05 \text{ mm}^2$$

$$\text{area of } \Delta PQS = \frac{1}{2} \times QS \times PT$$

$$= \frac{1}{2} \times 10 \times 19.36 \quad (PT = PR - RT = 20 - 0.64 = 19.36 \text{ mm})$$

$$= 96.8 \text{ mm}^2$$

$$\text{So, Reinforcement area (A}_R\text{)} = (\text{Area of sector PQRS}) - (\text{Area of } \Delta PQS)$$

$$= 101.05 - 96.8$$

$$A_R = 4.25 \text{ mm}^2$$

$$\text{So, \% dilution} = \left(\frac{A_P}{A_P + A_R} \right) \times 100$$

$$= \left(\frac{14.48}{14.48 + 4.25} \right) \times 100$$

$$\% \text{ dilution} = 77.30\%$$

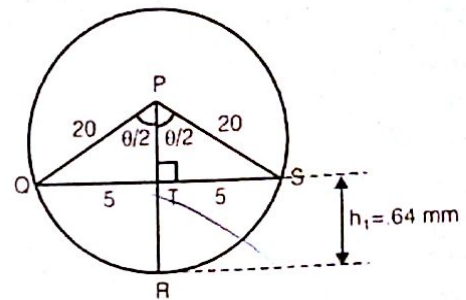


Fig. 6.14

Example : 6.8

Welding of C40 steel plate of 10 mm thickness required a current of 160 Amps, while it was 360 amps when the plate thickness was increased by 50%. Estimate the welding current for 8 mm thickness of same material.

Solution :

Given,

Current requirement for 10mm thick plate = 160 Amps.

Current requirement for 15mm thick plate = 360 Amps.

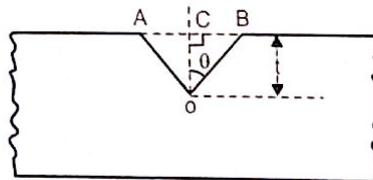


Fig. 6.15

$$\text{area of weld} = \frac{1}{2} \times AB \times OC$$

$$= \frac{1}{2} \times (t \times \tan \theta) \times 2 \times t$$

$$= t^2 \tan \theta$$

Let welding speed = v

So, Volume of weld = $(t^2 \tan \theta) v$

as volume of weld $\propto (\text{current})^2$

$$v(t^2 \tan \theta) \propto I^2$$

$$\Rightarrow I \propto t$$

$$\Rightarrow I = a + bt$$

at $t = 10 \text{ mm}$, $I = 160 \text{ A}$

$$\Rightarrow 160 = a + 10b \quad \dots(1)$$

at $t = 15 \text{ mm}$, $I = 360 \text{ A}$

$$\Rightarrow 360 = a + 15b \quad \dots(2)$$

Subtract (1) from (2),

$$200 = 5b$$

$$\Rightarrow b = 40$$

From equation (1)

$$160 = a + (10 \times 40)$$

$$\Rightarrow a = 160 - 400 = -240$$

$$\Rightarrow I = -240 + 40t$$

So, at thickness $(t) = 8 \text{ mm}$

$$I = -240 + (40 \times 8)$$

$$I = 80 \text{ Amps.}$$

$$\Rightarrow \text{Welding current} = 80 \text{ Amps.}$$

6.4.3 Submerged Arc Welding (SAW)

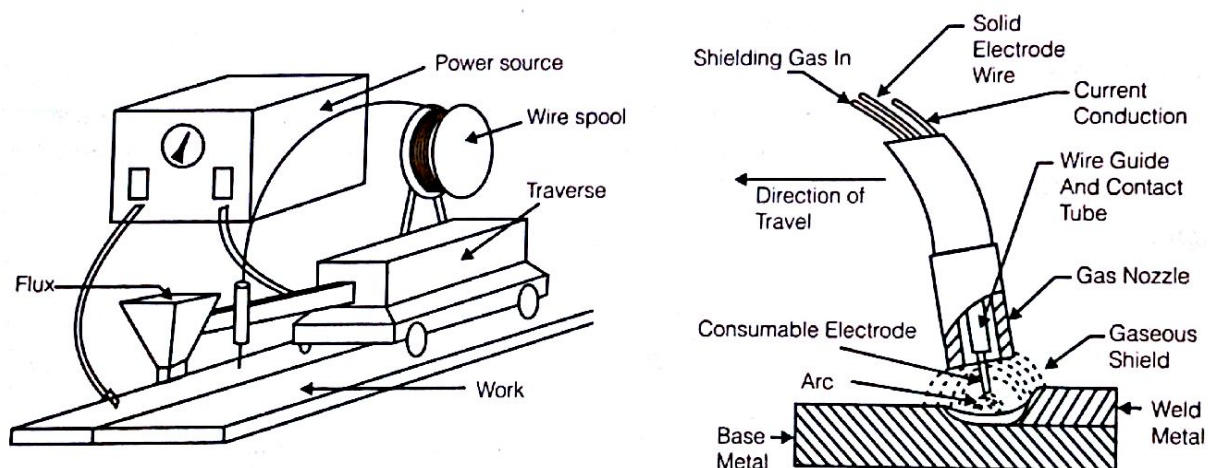


Fig. 6.16 : (a) and (b) Welding using SAW process

This is semi-automatic version of SMAW process which can produce long weld runs. In this type of welding electrode is in the form of spool of copper coated wire and granular flux is used. Copper is coated to increase the conductivity of wire. Powdered flux is initially poured into the welding area and arc is maintained within the pool of flux. This minimizes the Spatter of liquid

metal and suppresses the intense ultra violet radiation. Flux also acts as a thermal insulator by deep penetration of heat into the work piece. Flux is fed on weld zone by gravity through flow nozzle, a long continuous weld can be performed. It is mainly used in the down hand welding position in a semi-automatic welding process and the feeding of electrode towards the weld pool is controlled by machine. The welds obtained by this process are stronger than the base plate, if done carefully.

The metals most widely welded through this process are low carbon steels, low alloy steels, stainless steels and high alloy steels. It is extensively used in joints in thick plates in pressure vessels, ships, bridges, structural work, welded pipes and nuclear reactors. It can not be used for plates less than 5mm thick. The process is also used to make LPG cylinders.

6.4.4 Gas Tungsten Arc Welding (GTAW) or Tungsten Inert Gas Welding (TIG)

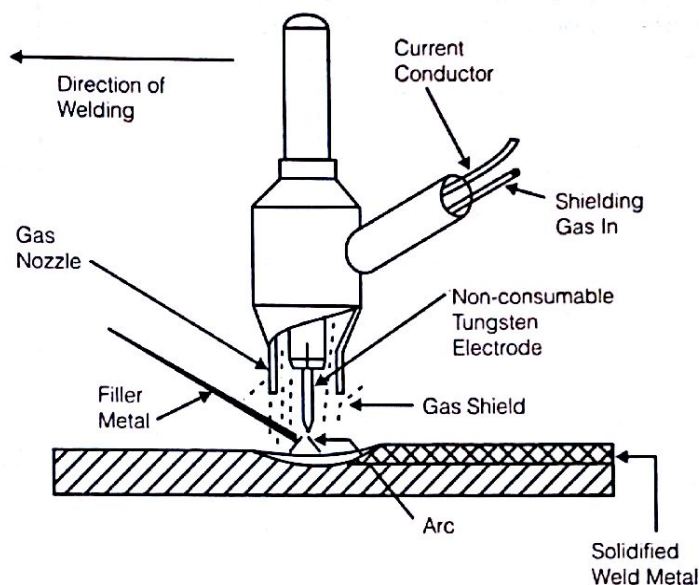


Fig. 6.17 : Tungsten inert gas welding (TIG)

In GTAW process the electrode is non consumable and the purpose of it is only to create an arc. A separate filler metal rod is used to deposit the material. This was primarily invented to weld alloys of Aluminium and Magnesium. Aluminium is very difficult to weld because as soon as it is exposed to atmosphere it forms a layer over it. To weld these materials work piece should be given negative polarity and electrode positive polarity. As the electrons are coming out of the work piece, peels of the ceramic layer and fresh Aluminium comes in contact with the arc. This phenomenon is called cathodic cleaning. Where ever electron bombards two-third heat will be generated, one-third heat is generated at the negative electrode and in case of GTAW when more heat is produced at the tungsten electrode it gets eroded and tungsten particles mixes with the bead making it brittle.

A pool of inert gases like Helium and Argon provides the protective covering to the molten metal. This reverse polarity is also used to weld very thin sheets because when the development of heat over work piece material is more, holes will be produced in the material and there will not be any welding. The torches for carrying current beyond 100 amperes are usually water cooled. Arc initiation is normally done by touching the electrode on a graphite block. The gas nozzle of a GTAW torch is its weakest part and is fastened to the torch body by threaded connection. These nozzles are generally made of ceramic material.

This process is used to weld in all positions and is extensively used for welding aluminium, magnesium, stainless steels, copper, Nimonic alloys, Monel, inconel etc. it is especially used in aircraft industry, chemical plant and nuclear plant.

Comparison of Different Electrode polarities:

	DC, electrode positive	DC, electrode negative	AC
1. Penetration	 shallow	 Deep	 Intermediate
2. Heat generation	2/3rd at electrode, 1/3rd at workpiece	1/3rd at electrode, 2/3rd at workpiece	50% on both
3. Metal deposition rate	High	Low	Intermediate
4. Thickness of work to be welded	Thin sheets	Thick sheets	Intermediate
5. Stable smaller arc	Easier	Easier	Difficult
6. Arc blow	Severe	Severe	Insignificant

As the thickness of work decreases negative polarities should be given for work otherwise due to development of excessive heat holes will develop in the sheet. To control the metal deposition rate GTAW process is used. If the thickness further decreases, the operating current should decrease.

Electrode Penetration in GTAW : If negative polarity is given to electrode it should be grinded to a point to increase the density of current which leads to deeper penetration. If the electrode is given positive polarity, diameter of tip is increased to minimize the electrode erosion.

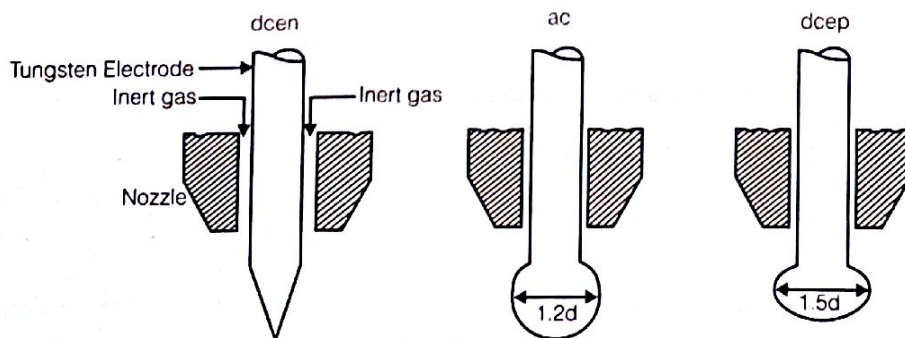


Fig. 6.18 : Shapes of tungsten electrodes

The selection of the electrode should be good to get the best results. The extension of the cup should be approximately equal to the inside diameter of the cup or slightly more in case of fillet welds. Otherwise the shielding effect will be reduced. Instead of GTAW in Gas metal Arc Welding (GMAW) tungsten electrode is replaced by a consumable electrode which is in the form of spool.

6.4.5 Arc Blow

Due to fixed polarity magnetic lines forms in the work piece material. Upon welding at the center of the work magnetic lines will be equally distributed on both sides. So arc will be straight. But

while welding near the edges, since most of the magnetic lines will be concentrated in the material, arc will be deflected towards the workpiece. This phenomenon is called Arc Blow which results in severe spatter and improper bead geometry.

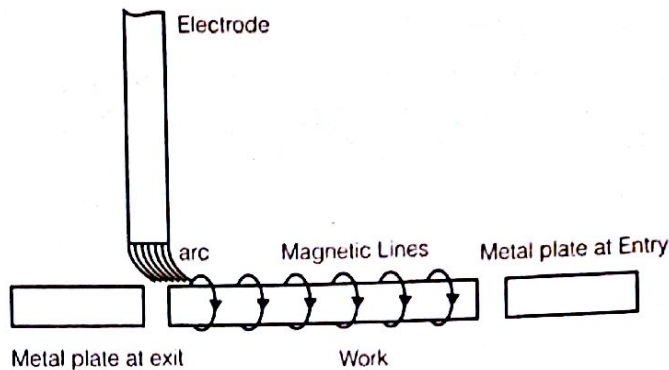


Fig. 6.19 : Arc blow due to magnetic field

Arc Blow phenomenon will be more intensified while welding with DC with bare electrodes. To avoid this phenomenon metal plates are kept at the entry and at the exit called Tab in and Tab out. These plates also minimize the end defects. Arc Blow phenomenon may also appear when large piece of iron is present at the welding site.

6.4.6 Duty Cycle

It is the time span in successive 10 min interval during which current can be drawn from the transformer, after that there should be a compulsory break otherwise the temperature of its essential components will increase. Usually 60% duty cycle is the standard industrial rating. A power source with such a rating can supply its rated output for 6 minutes in every ten minute interval of its operation.

$$I^2 D = \text{Constant}$$

where

D = Duty cycle and

I = Current

6.4.7 Plasma Arc Welding (PAW)

Plasma is the pool of ionized gas. Initially the arc is being created between Tungsten electrode and the work piece, plasma gases like 'N' by taking energy from the spark converts into plasma. The temperature of plasma is around 50000°C but for the welding process it is restricted to 20000°C. This high temperature arc when it impinges upon the work piece results in reuniting of electrons and ions to form atomic and then molecular gas, releasing heat in the process which is thus utilized for welding. Due to increase source of heat penetration will through and without spreading the heat affected zone it is called keyhole phenomenon, this phenomenon will ensure 100% penetration and gives wine glass weld bead. More intense the source of heat, deeper will be the penetration and maximum can be the welding speed and hence lesser will be the heat affected zone. A separate filler rod is used to deposit the material. When plasma torch is used for cutting it is called metal melting process and not oxidation process. Plasma arc is concentrated because it is fed through a small nozzle. The energy is obtained from a dc power source of the constant current type having an open circuit voltage of 70 – 80 volts and duty cycle of 60%. There are two types plasma arc welding. In the transferred – arc method the work piece is welded as

part of the electrical circuit. The arc transfers from the electrode to the work piece. In the non transferred type the arc occurs between the electrode and the nozzle and the heat is carried to the work piece by plasma gas. The thermal transfer mechanism is similar to that for Oxyfuel flame. The major application of the process is in welding stainless steel, titanium, having very high melting points and super alloys. Commercially it is used in aeronautical industry, precision instrument industry and jet engine manufacturing. This plasma arc welding has serious drawbacks. For example the intense arc results in extensive ultra violet and infra - red radiation which can harm the skin.

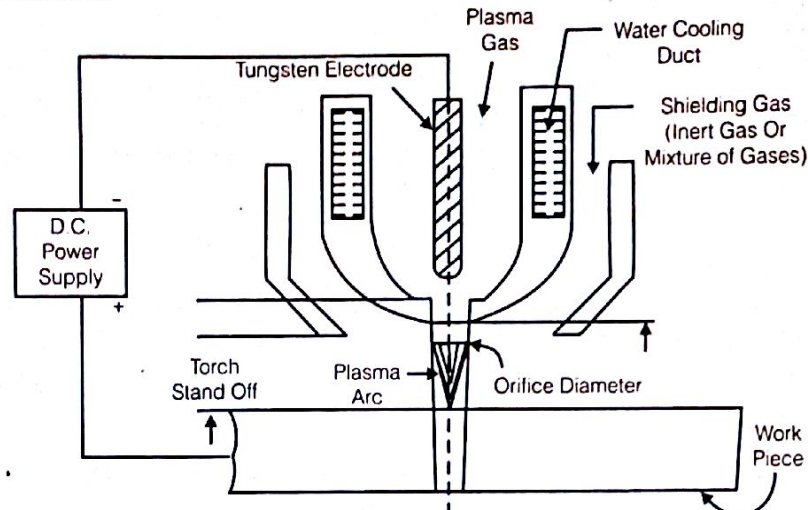


Fig. 6.20 : (a) Set up of plasma arc welding

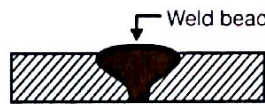


Fig. 6.20 : (b) Wine glass bead structure in PAW

6.4.8 Electro slag/Electro gas Welding

Initially the arc is being created between starting block and the Copper coated electrode wire followed by addition of flux. Welding progresses in the vertical direction and due to that temperature of the molten pool keeps on increasing. A pair of water cooled cu shoes is being provided on the sides to avoid any spillage of liquid metal to the sides. Once the temperature of the molten pool reaches a particular value arc is switched off and the molten pool is so hot that it starts consuming the wire without any arc. Temperature is controlled in this fashion to minimize the heat affected zone. If the heat effected zone increases it may cause distortion of the plate.

The point when molten metal is not able to consume any more wire, arc is restarted again. Restarting the arc is easy on electro gas welding. In electro gas welding an inert gas is used in place of slag or flux. The duty cycle of the transformer is 100% and electrode should be given positive polarity. Both AC and DC power sources are used with a rating of 1000 amperes at an open circuit voltage of 55 volts and duty cycle of 100 percent.

The process is used to join two thick plates along the edges. The major application is in ship building. Welding is done with joint in vertical position. It can be used for welding plates of thickness 20mm to 40mm. It is also used extensively in the heavy ferrous industry. This finds

extensive use in the construction of pressure vessels, press frames, water turbine and heavy plate fabrication industries.

Welding current depends on welding voltage and electrode feed rate, it increases with it. Increase in welding current increases the welding speed, but higher welding current may cause cracking. Welding voltage affects the depth of penetration and stable operation of the process. Excessive voltage causes overheating of the metal, gassing of the slag pool, and even sparking.

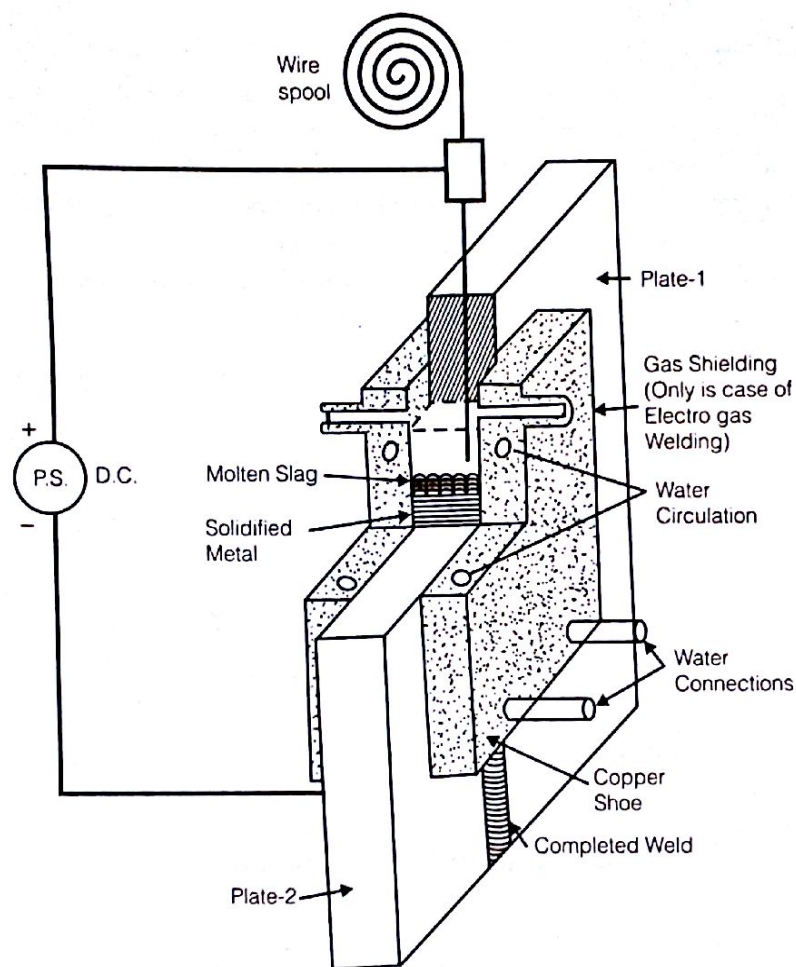


Fig. 6.21 : Electro Slag Welding

6.5 RESISTANCE WELDING

Some of the important resistance welding processes are :

- A. Spot
- B. Projection
- C. Seam
- D. HFRW/HFIW
- E. Flash butt welding

The resistance welding is produced by means of electrical resistance across the two components to be joined. The heat generated in this process is given by

$$H = I^2RT$$

H = heat generated in joules

I = current in amperes.
 R = resistance in ohms.
 t = time of current flow in seconds

The welds produced by resistance welding are normally without the addition of any filler material, electrodes and shielding gases.

6.5.1 Spot welding

A pair of sheet is held between two copper electrodes. Indentation is produced over the sheet by applying the pressure on the electrodes. Due to indentation there will not be any air gap between electrode and the sheet. Step down transformers are used in resistance welding, in the secondary winding of which there is single turn. When a high current is passed through conductors, maximum resistance will be there at the interface between the two sheets due to presence of air gap. As a result of that material in both the sheets will be liquified and a spot (nugget) will be formed. Kickless cables are used to supply the current for the safety of operator. Rocker arm type machines are used for smaller parts and press type are used for larger work pieces.

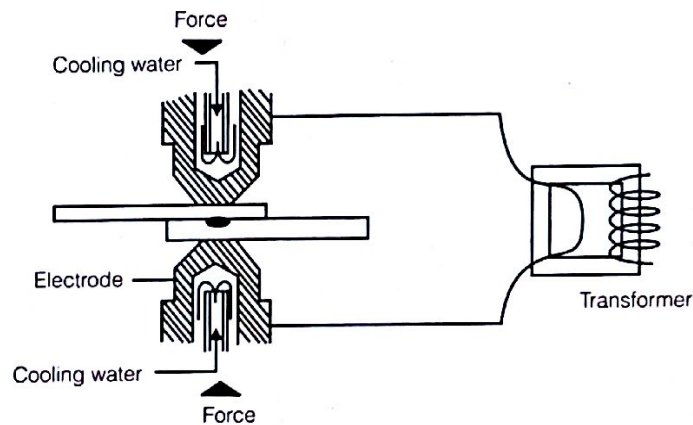


Fig. 6.22 : (a) Resistance welding set up

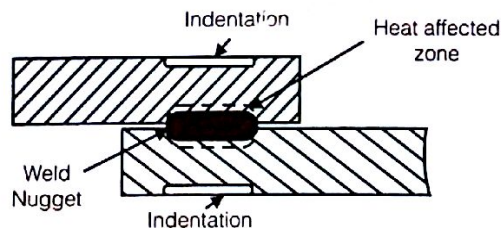


Fig. 6.22 : (b) Spot welding nugget

The diameter of the nugget is $d_n = 6\sqrt{t}$

Height of the nugget is $h_n = 2t - \text{indentation}$

Spot welding is mainly used for lap welding of thin sheets particularly in the welding of automobile and refrigerator bodies and high quality work in automobile engines.

6.5.2 Projection welding

To make number of spot welds in one set up projection welding is used. These projections are made by EMBOSSING process by the flow of current. The projection materials become soft and the pressure on the electrode is suddenly increased and projections are allowed to collapse on the other sheet. During this stage the sheet which has projections tends to be hotter. So projections are provided in the thicker sheet or the sheet which has higher thermal conductivity. There are so many projections: round button or dome type, ring type, elongated projection, shoulder projection, radius projection and cross wires. Equipment used for projection welding is similar to that for spot welding except that the rod electrodes are replaced by flat copper plates. Projection welding reduces the amount of current and pressure needed to achieve a good bond between the two pieces, with consequential less chance of shrinkage and distortion in the areas around the weld zone.

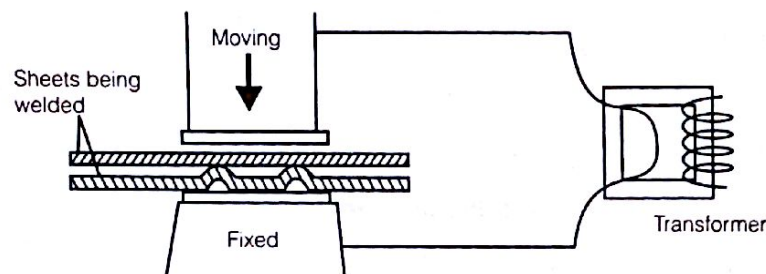


Fig. 6.23 : Projection welding set up

6.5.3 Seam Welding

Spot welding is meant for making leak proof welds. To make overlapping spot weld (leak proof welding) electrodes are taken in the form of wheels. Such weld is called Stitch Weld. To produce stitch welds at higher speeds seam welding is used. In seam welding the electrodes used in the form of rollers or wheels, due to shunting of current through the already made welds, the current required is higher than in normal spot welding. Pressure is applied to fuse metal properly into the nugget as in spot welding. Seam welding is a continuous process. Electrodes get overheated and hence need constant cooling. It is done externally by the impinging water jets. Seam welding is capable of welding thin materials of thickness between the ranges of 2.5 to 4.7 mm.

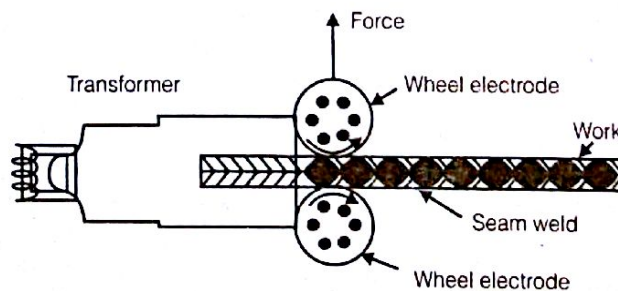


Fig. 6.24 : Seam welding set up

Example : 6.9

Two sheets of 1.5 mm thickness are to be spot welded by passing a current of 10,000 A for 0.1 sec. The maximum indentation allowed is 10% of sheet thickness. The density of spot weld nugget is 8 gm/cm³. If 1380 Joules are required to melt 1 gm of steel. Calculate the efficiency if effective resistance to be 200 micro ohm.

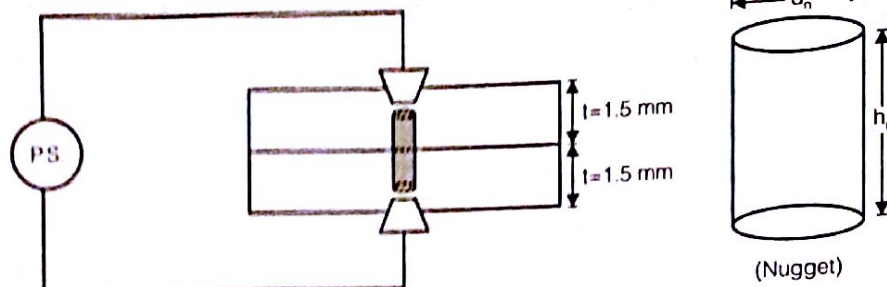
Solution :

Given,

$$\text{Current (I)} = 10,000 \text{ A}$$

$$\text{Resistance (R)} = 200 \mu\Omega = 200 \times 10^{-6} \Omega$$

$$\text{time (t}_1\text{)} = 0.1 \text{ s}$$

**Fig. 6.25 : Seam welding set up**

So, total heat supplied

$$\begin{aligned} (H_s) &= I^2 R t_1 \\ &= (10,000)^2 \times (200 \times 10^{-6}) \times 0.1 \\ H_s &= 2000 \text{ J} \end{aligned}$$

as, we know, diameter of nugget (d_n) = $6 \times \sqrt{t} = 6 \times \sqrt{1.5}$

$$d_n = 7.34 \text{ mm}$$

Height of nugget

$$\begin{aligned} (h_n) &= 2 \times (\text{thickness} - \text{indentation}) \\ &= 2 \times \left(1.5 - \frac{10 \times 1.5}{100} \right) \\ &= 2 \times 1.5 \times 0.9 \\ h_n &= 2.7 \text{ mm} \end{aligned}$$

So, volume of nugget

$$(V_n) = \frac{\pi}{4} \times d_n^2 \times h_n$$

$$V_n = \frac{\pi}{4} \times 7.34^2 \times 2.7$$

 $\Rightarrow$

$$V_n = 114.24 \text{ mm}^3$$

or

$$V_n = 114.24 \times 10^{-3} \text{ cm}^3$$

as density of nugget = 8 gm/cm³

So,

mass of nugget = density $\times$ volume

$$= 8 \times 114.24 \times 10^{-3}$$

$$\text{mass of nugget} = 0.913 \text{ gm}$$

as 1380 joules are required to melt 1 gm of steel

$$\text{So total heat required to melt} = 1380 \times 0.913$$

$$= 1261.28 \text{ Joules}$$

So,
$$\text{efficiency } (\eta) = \frac{\text{Heat Required to melt}}{\text{Heat Supplied to melt}} \times 100$$

$$= \frac{1261.28}{2000} \times 100$$

$$\eta = 63.06\%$$

So,
$$\text{efficiency} = 63.06\%$$

Example : 6.10

Spot welding of two 1 mm thick sheets of steel (density = 8000 kg/m³) is carried out successfully by passing a certain amount of current for 0.1 second through the electrodes. The resultant weld nugget formed is 5 mm in diameter and 1.5 mm thick. If the latent heat of fusion of steel is 1400 kJ/kg and the effective resistance in the welding operation is 200 $\mu\Omega$, what is the current passing through the electrodes.

Solution :

Given,

thickness of sheet (t) = 1 mm

density of steel (ρ) = 8000 kg/m³

time (t_1) = 0.1 s

diameter of nugget (d_n) = 5 mm

thickness of nugget (h_n) = 1.5 mm

Latent heat of fusion of steel = 1400 kJ/kg

Resistance (R) = 200 $\mu\Omega$

Volume of Nugget is given by,

$$\text{Volume} = \frac{\pi}{4} \times d_n^2 \times h_n = \frac{\pi}{4} \times 5^2 \times 1.5$$

$$\text{Volume of nugget} = 29.45 \text{ mm}^3$$

$$\text{Volume of nugget} = 29.45 \times 10^{-9} \text{ m}^3$$

$$\begin{aligned} \text{Mass of Nugget} &= \text{density} \times \text{volume of nugget} \\ &= 8000 \times 29.45 \times 10^{-9} \end{aligned}$$

$$\text{Mass of Nugget} = 2.356 \times 10^{-4} \text{ kg}$$

as Latent heat of fusion = 1400 kJ/kg

So, total heat of fusion = 1400 $\times$ mass

$$= 1400 \times 2.356 \times 10^{-4} \text{ kJ} = 0.329867 \text{ kJ}$$

$$\text{Total heat} = 329.867 \text{ J} \quad \dots(1)$$

Total heat is also given as $H = I^2 R t_1$

$$H = I^2 \times 200 \times 10^{-6} \times 0.1 \quad \dots(2)$$

Equation (1) and (2);

$$I^2 \times 200 \times 10^{-6} \times 0.1 = 329.867$$

$$I^2 = 16.493 \times 10^6$$

$$\Rightarrow I = 4061.2 \text{ Amp.}$$

$$\Rightarrow \text{Current passing through the electrodes} = 4061.2 \text{ Amp.}$$

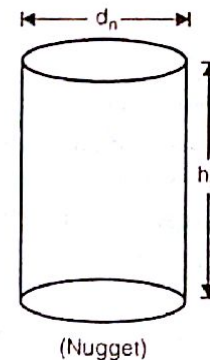


Fig. 6.26 : Spot welding set up

Example : 6.11

In an arc welding process, the voltage and current are 25 V and 300 A respectively. The arc heat transfer efficiency is 0.85 and welding speed is 8 mm/sec. What is the net heat input (in J/mm).

Solution :

Given, Voltage (V) = 25 volts
 Current (I) = 300 Amp.
 Arc heat transfer efficiency (η_T) = 0.85
 Welding speed (v) = 8 mm/s
 Let net heat input = H_1 J/mm
 Total heat supplied i.e. Power = $V \times I$
 $= 25 \times 300 = 7500$ W

as heat transfer efficiency is 0.85 so net

$$\begin{aligned} \text{heat input at the bead is} &= \eta_T \times 7500 \\ &= 0.85 \times 7500 \end{aligned}$$

$$\text{Heat input} = 6375 \text{ Watts} \quad \dots(1)$$

Heat input is also given as

$$\text{Heat input} = H_1 \times \text{Welding speed} = H_1 \times 8 \quad \dots(2)$$

From (1) and (2)

$$H_1 \times 8 = 6375$$

$$\Rightarrow H_1 = 796.875 \text{ J/mm}$$

$$\text{So Net heat input} = 796.875 \text{ J/mm}$$

Example : 6.12

Two metallic sheets, each of 2.0 mm thickness, are welded in a lap joint configuration by resistance spot welding at a welding current of 10 kA and welding time of 10 millisecond. A spherical fusion zone extending up to the full thickness of each sheet is formed a properties of the metallic sheets are given as :

ambient temperature = 293 K

melting temperature = 1793 K; Density = 7000 kg/m³

latent heat of fusion = 300 kJ/kg; Specific heat = 800 J/kgK

Assume :

1. contact resistance along sheet-interface is 500 micro-ohm and along electrode-sheet interface is zero;
2. no conductive heat loss through the bulk sheet materials; and
3. the complete weld fusion zone is at the melting temperature.

What is the melting efficiency (in %) of the process?

Solution :

Given,

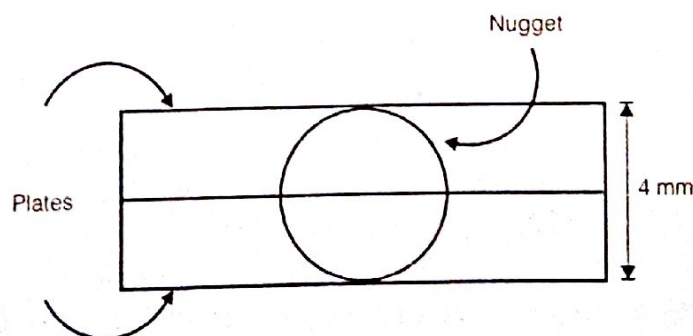


Fig. 6.27 : Seam welding set up

Thickness of each plate (t) = 2 mm

Welding current (I) = 10 kA = 10,000 A

Welding time (t_1) = 10 millisecond = 10×10^{-3} s

Spherical fusion zone is formed upto full thickness of each plate

ambient temperature (T_{amb}) = 293 K

Melting temperature (T_{MP}) = 1793 K

density (ρ) = 7000 kg/m³

Latent heat of fusion (L) = 300 kJ/kg = 300,000 J/kg

Specific heat (c) = 800 J/kg K

Contact Resistance (R) = 500 micro ohm = $500 \times 10^{-6} \Omega$

Total heat supplied (H) = $I^2 R t_1$
 $= (10000)^2 \times 500 \times 10^{-6} \times 10 \times 10^{-3}$
 $= 500 \text{ J}$

As nugget is of spherical shape with radius of 2mm.

$$\text{Volume of nugget} = \frac{4}{3} \pi r^3 = \frac{4}{3} \times \pi \times 2^3$$

$$= 33.51 \text{ mm}^3$$

$$\Rightarrow \text{Volume of nugget} = 33.51 \times 10^{-9} \text{ m}^3$$

$$\text{Mass of nugget (m)} = \text{density} \times \text{volume}$$

$$= 7000 \times 33.51 \times 10^{-9} \text{ kg}$$

$$m = 2.345 \times 10^{-4} \text{ kg}$$

Total heat required to form nugget is sum of heat required to raise the temperature from ambient to melting point (sensible heat) and heat required to change phase (Latent heat)

$$\Rightarrow \text{total heat required} = \text{sensible heat} + \text{latent heat}$$

$$= mC \Delta T + mL$$

$$= m [C(T_{MP} - T_{amb}) + L]$$

$$= 2.345 \times 10^{-4} [800 (1793 - 293) + 300,000]$$

$$\text{Total heat required to melt} = 351.75 \text{ J}$$

$$\Rightarrow \text{melting efficiency} = \frac{\text{total heat required to melt}}{\text{total heat supplied}} \times 100$$

$$= \frac{351.75}{500} \times 100$$

$$\text{melting efficiency} = 70.35\%$$

Example : 6.13

Two steel sheets of thickness one mm are welded by resistance projection welding technique. A current of 30,000 A for 0.005 second is made to flow. The effective resistance of joint can be taken as 100 micro ohms. The joint can be considered as a cylinder of diameter 5 mm and height 1.5 mm. The density of steel is 0.00786 gm/mm³. The heat needed for welding steel is 10 J/mm³. Calculate the efficiency of welding.

Solution :

Given,

$$\begin{aligned}
 \text{thickness of each sheet (t)} &= 1 \text{ mm} \\
 \text{current (I)} &= 30,000 \text{ A} \\
 \text{time (t}_1\text{)} &= 0.005 \text{ s} \\
 \text{Resistance (R)} &= 100 \text{ micro ohms} \\
 &= 100 \times 10^{-6} \Omega
 \end{aligned}$$

Welding is done by resistance projection welding process.

Nugget or spot generated is of cylindrical shape.

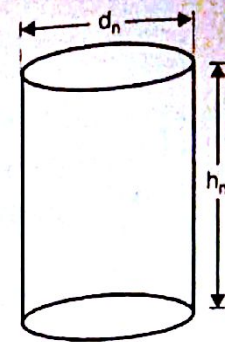
$$\begin{aligned}
 \text{diameter of nugget (d}_n\text{)} &= 5 \text{ mm} \\
 \text{Height of nugget (h}_n\text{)} &= 1.5 \text{ mm} \\
 \text{density of steel (}\rho\text{)} &= 0.00786 \text{ gm/mm}^3 \\
 \text{Heat needed for welding steel} &= 10 \text{ J/mm}^3 \\
 \text{Total heat supplied for weld} &= I^2 R t_1 \\
 &= (30,000)^2 \times 100 \times 10^{-6} \times 0.005 \\
 \text{Total heat supplied for weld} &= 450 \text{ J}
 \end{aligned}$$

$$\begin{aligned}
 \text{Volume of cylindrical nugget} &= \frac{\pi}{4} \times d_n^2 \times h_n \\
 &= \frac{\pi}{4} \times 5^2 \times 1.5 = 29.45 \text{ mm}^3
 \end{aligned}$$

$$\begin{aligned}
 \text{So, heat needed for welding steel} &= 10 \times \text{volume} \\
 &= 10 \times 29.45 \text{ J} \\
 \text{Heat needed} &= 294.5 \text{ J}
 \end{aligned}$$

$$\begin{aligned}
 \text{So, efficiency of welding} &= \frac{\text{Heat needed}}{\text{Heat supplied}} \times 100 \\
 &= \frac{294.5}{450} \times 100
 \end{aligned}$$

$$\text{Efficiency} = 65.44\%$$



Cylindrical Nugget

Fig. 6.28 : Projection welding**Example : 6.14****What are the common defects found in welding? Explain their causes and remedies.**

A spot welding obtained with a current of 35,000 A for a period of 0.01 sec. If the effective resistance of the joint be taken as 120 micro ohms, and if the joint can be considered as a cylinder of 6 mm diameter and 2.5 mm in height, calculate the heat distributed to the surroundings.

Take heat required for melting steel as 10 J/mm³.

Solution :

Given,

$$\begin{aligned}
 \text{Current (I)} &= 35,000 \text{ A} \\
 \text{time (t}_1\text{)} &= 0.01 \text{ s} \\
 \text{Resistance (R)} &= 120 \mu\Omega = 120 \times 10^{-6} \Omega
 \end{aligned}$$

Nugget formed is cylindrical with

$$\text{diameter (d}_n\text{)} = 6 \text{ mm}$$

$$\begin{aligned}
 \text{height } (h_n) &= 2.5 \text{ mm} \\
 \text{Total heat required for melting steel} &= 10 \text{ J/mm}^3 \\
 \text{Total heat supplied} &= I^2 R t_1 \\
 &= (35000)^2 \times 120 \times 10^{-6} \times 0.01 \\
 \text{Total heat supplied} &= 1470 \text{ J} \\
 \text{Volume of cylindrical nugget} &= \frac{\pi}{4} \times d_n^2 \times h_n \\
 &= \frac{\pi}{4} \times 6^2 \times 2.5 = 70.68 \text{ mm}^3
 \end{aligned}$$

So heat required for melting steel = $10 \times 70.68 = 706.8 \text{ J}$

So, heat lost surrounding per nugget = $1470 - 706.8 = 763.2 \text{ J}$

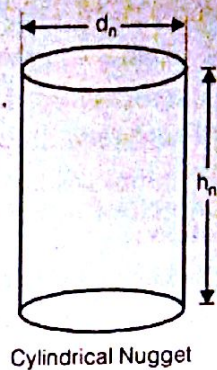


Fig. 6.29 : Spot welding

Example : 6.15

For resistance spot welding of two aluminium sheets, each 2 mm thick, a current of 5000 A was passed for 0.15 sec. The total resistance was estimated to be $75 \mu\Omega$ and the nugget diameter and thickness were measured to be 5 mm and 2.5 mm respectively. What would be the proportion of heat energy utilized for welding if the melting energy per unit volume for aluminium is taken as 2.9 J/mm^3 ?

Solution :

Given,

$$\begin{aligned}
 \text{thickness of each plate } (t) &= 2 \text{ mm} \\
 \text{current } (I) &= 5000 \text{ A} \\
 \text{time } (t_1) &= 0.15 \text{ s} \\
 \text{Resistance } (R) &= 75 \mu\Omega = 75 \times 10^{-6} \Omega \\
 \text{Nugget diameter } (d_n) &= 5 \text{ mm} \\
 \text{Nugget thickness } (h_n) &= 2.5 \text{ mm} \\
 \text{Melting energy required per unit volume} &= 2.9 \text{ J/mm}^3
 \end{aligned}$$

$$\begin{aligned}
 \text{Volume of nugget} &= \frac{\pi}{4} \times d_n^2 \times h_n \\
 &= \frac{\pi}{4} \times 5^2 \times 2.5 = 49.087 \text{ mm}^3
 \end{aligned}$$

$$\begin{aligned}
 \text{So, melting energy required} &= 2.9 \times \text{volume} \\
 &= 2.9 \times 49.087 \text{ J}
 \end{aligned}$$

$$\text{Total energy required to melt} = 142.353 \text{ J}$$

$$\begin{aligned}
 \text{Total energy supplied} &= I^2 R t_1 \\
 &= (5000)^2 \times 75 \times 10^{-6} \times 0.15
 \end{aligned}$$

$$\text{Total energy supplied} = 281.25 \text{ J}$$

$$\text{So, proportion of heat utilized} = \frac{\text{Heat Required}}{\text{Heat Supplied}} \times 100$$

$$= \frac{142.353}{281.25} \times 100 = 50.61$$

$$\Rightarrow \text{Proportion of Heat utilized} = 50.61\%$$

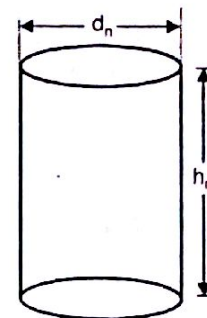


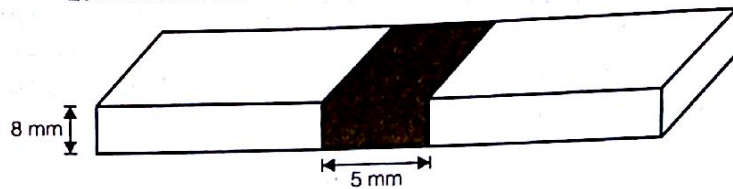
Fig. 6.30 : Spot welding

Example : 6.16

Two 8 mm thick steel plates are placed 5 mm apart and welded by a butt joint. Welding is carried out at 20 volts and at speed of 5 mm/s. Heat transfer efficiency is 0.80. If the heat required to melt steel is 10 J/mm³ and melting efficiency is 0.625, then the weld current (In Amp) will be

Solution :

Given, thickness of each plate (t) = 8 mm
 distance between plates (d) = 5 mm
 voltage (V) = 20 volts
 Speed of weld (v) = 5 mm/s
 Heat transfer efficiency (η_T) = 0.80
 Heat required to melt metal = 10 J/mm³
 Melting efficiency (η_m) = 0.625
 Let weld current = I Amp.

**Fig. 6.31**

Total heat energy supplied = $V \times I$

$$= 20 \times I \frac{\text{Joules}}{\text{s}}$$

as heat transfer efficiency is 0.80

So, total heat energy supplied to bead = $0.80 \times 20 \times I$

Heat supplied = 16I Watt

Volume of metal melted per second = (Area) $\times$ (Velocity of weld)

$$= (8 \times 5) \times (5)$$

$$= 200 \text{ mm}^3/\text{s}$$

As heat required to melt = 10 J/mm³

So, total heat required to melt = 10×200

$$= 2000 \text{ J/s}$$

as melting efficiency = 0.625

$$\eta_{\text{melting}} = \frac{\text{Heat required}}{\text{Heat supplied}}$$

$$0.625 = \frac{2000}{16I}$$

$$\Rightarrow I = 200 \text{ Amp.}$$

$$\Rightarrow \text{Weld Current} = 200 \text{ Amp.}$$

Example : 6.17

In spot welding (pulsed laser) of aluminium plates (density = 2700 kg/m^3 , specific heat (c) = 896 J/kg K , melting temperature = 933 K , latent heat of melting = 398 kJ/kg) at a temperature of 30°C , a pulse with energy of 0.5 J is focussed onto an area of 0.05 mm^2 . If the entire energy is coupled into the material. What will be the depth of weld? Assume the cross-section area of the weld circular and is uniform throughout its depth and only heat conduction in the direction of penetration.

Solution :

Given, density of plate = 2700 kg/m^3
 specific heat (c) = 896 J/kg K
 Melting temperature (T_{MP}) = 933 K
 Ambient temperature (t_{amb}) = $273 + 30 = 303 \text{ K}$

$$\text{Latent heat of melting (L)} = 398 \frac{\text{kJ}}{\text{kg}} = 398 \times 1000 \frac{\text{J}}{\text{kg}}$$

Let depth of spot = $d \text{ mm}$

as nugget formed has circular cross-section throughout its depth i.e. it is cylindrical

Volume of Nugget = (cross-section area) $\times$ depth

Volume of Nugget = $(0.05 d) \text{ mm}^3$

Mass of Nugget = density $\times$ volume

$$= 2700 \times 0.05d \times 10^{-9} = 135d \times 10^{-9} \text{ kg}$$

Amount of heat required to melt is the sum of total heat required to increase temperature of metal from ambient temperature to melting point and heat required to melt.

$$\begin{aligned} \Rightarrow \text{Heat required to melt} &= mC \Delta T + mL \\ &= m [C (T_{MP} - T_{amb}) + L] \\ &= 135d \times 10^{-9} [896 (933 - 303) + 398 \times 1000] \end{aligned}$$

$$\text{Heat required to melt} = 0.1299d \text{ J}$$

Now Heat required to melt = Heat energy supplied

$$0.1299d = 0.5$$

$$d = 3.849 \text{ mm}$$

$$\Rightarrow \text{depth of weld} = 3.849 \text{ mm Ans.}$$

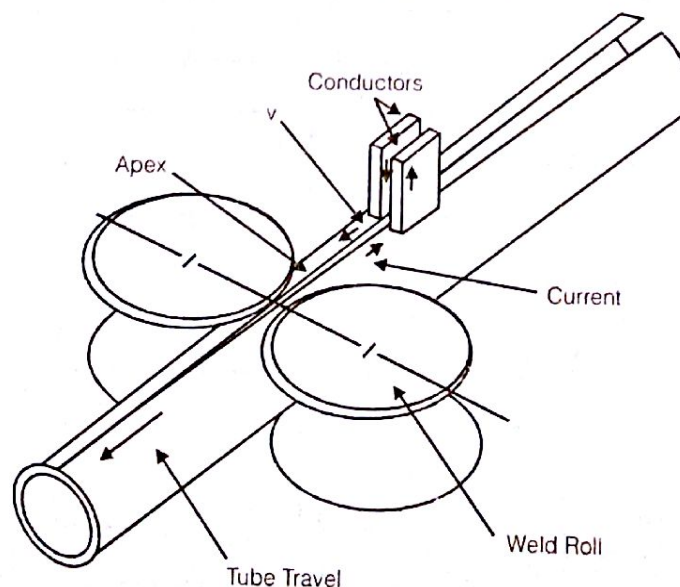
6.5.4 High Frequency Resistance Welding (HFRW)

Fig. 6.32 : High frequency resistance welding process of tube making

Initially the steel is cut into the strips and as it approaches towards the concave rolls the sheet will bend in the form of a pipe. Mandrel is placed at the center so that sheet bends exactly in a cylindrical fashion. A pair of conductors is kept on both sides of edges and a high frequency current is passed. Due to skin effect current flows through low inductance rather than low resistance current is passed. This results in the heating of edges and when the pressure is applied by the i.e. through air gap. This results in the heating of edges and when the pressure is applied by the piece material, after welding some kilometers of pipe the blocks should be replaced. This process is used to make iron pipes.

6.5.5 Flash Butt Welding

Two workpieces are held together with the help of electrodes as shown in figure 6.33 and a very high current around 100000 A is passed through these conductors. By the production of flash, oxide layer from the ends will be removed and material will also become soft. Current is stopped and axial pressure is increased to make a joint. Weld is formed through plastic deformation. In this two clamps will be present to hold the work pieces, one is fixed and the other is movable so that they can adjust. After applying high force weld is achieved and metal is expelled forming a rough fin or flash around the joint. This can be removed by machining.

The process is extensively used for welding mild steels, medium carbon steels and alloy steels as well as non ferrous metals like Aluminium alloys and titanium. This process is suitable for end to end or edge to edge joining of sheets of similar or dissimilar metals 0.2mm to 25mm thick.

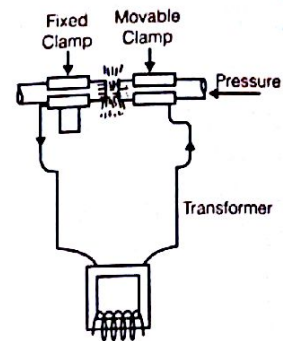


Fig. 6.33 : Principle of flash butt welding

6.6 SOLID STATE WELDING PROCESSES

6.6.1 Friction Welding

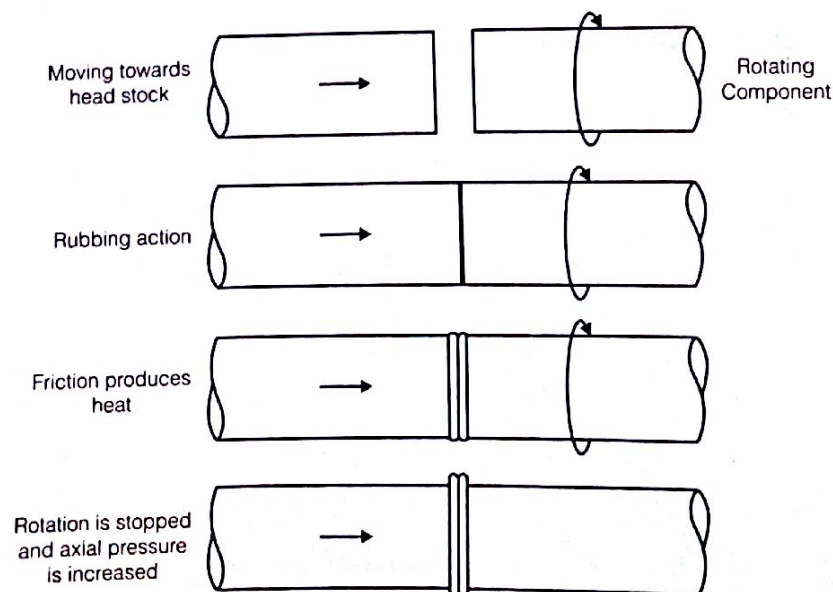


Fig. 6.34 : Steps in friction welding

The principle of this operation is changing mechanical energy into heat energy. Two samples are joined together along their axis by this process. One part is held in the chuck and the other is in the tail stock and the spindle is rotated at very high speed (around 5900 r.p.m). Both pieces are allowed to rub against each other and as a result of that heat will be produced. The material near edges will become softer and once it reaches particular temperature, breaks are applied and axial pressure is increased to cause the forging action and hence welding. No joint preparation is required for most of the non ferrous metals, since the rotating action is self cleansing. For some non ferrous metals, preparatory cleansing of the joint faces is important.

The weld zone is usually confined to a narrow region whose size depends upon

- the amount of heat generated
- the thermal conductivity of the materials and
- the mechanical properties of the materials at elevated temperatures.

The shape of the weld joint depends upon the rotational speed and on the axial pressure applied. Friction welding is the high speed process suited to production welding. When the interfaces are first brought into contact, maximum power is required for breaking up the surface film. The power required then falls and remains nearly constant while the joint is raised to welding temperature.

Bars of dissimilar metals and varying cross sections can be joined by this process. The major application of the process is in welding drill to the shank, welding engine valves to stem, axle to its hub etc.

6.6.2 Ultrasonic Welding

Heat affected zone is minimum in ultrasonic welding. High frequency vibrations are being produced by a transducer in the range of 20 to 60 KHz and are transported to the work with the help of sonotrode. Load is applied on the sonotrode tip with the help of pneumatic, hydraulic or a spring actuated device. Higher the frequency of vibration higher is the rate at which energy is transmitted. Due to ultrasonic energy oxide layer at the interface will be broken and there will be a fresh metal contact between the two work pieces. The temperature generated in the weld zone is usually 30-50% of the melting point of base metal.

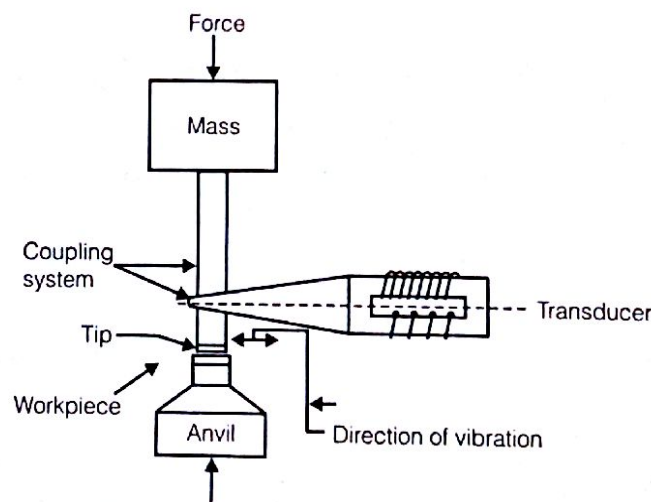


Fig. 6.35 : Components of Ultrasonic welding machine.

Ultrasonic welding equipment consists of two main parts, power source and a transducer. The power source converts the 50 Hz mains supply to a high frequency electric power and that is converted by the transducer to magnetic flux and then the kinetic motion which is amplified through a velocity transformer. This set up can be used for spot and seam welds. The major application of process is in armature winding, aluminum wire connectors in transducers and diodes.

6.6.3 Explosive Welding

Two plates can be joined together along the surface by this process. Two plates to be welded are placed at an inclination to each other, the angle vary from 1° - 10° . The thicker plate is called the target plate and the thinner plate is called flyer plate has a buffer plate of PVC or rubber, between it and the explosive. The charge is exploded by a detonator placed at one end of flyer plate. When the charge explodes, the flyer plate moves towards the target plate and Stand off distance is being provided for the initial momentum to develop in the flyer plate. Because of the movement with higher velocity pressure is produced at the interface. Under such high velocity and pressure the metal flows ahead of the joining front acting like a fluid jet resulting in a bond of the interlocking type. This interlocking is an essential aspect of an explosion welding and cause of strength. Flyer plate is kept at an angle to give direction to the weld and objective of buffer plate is to protect the flyer plate from explosive.

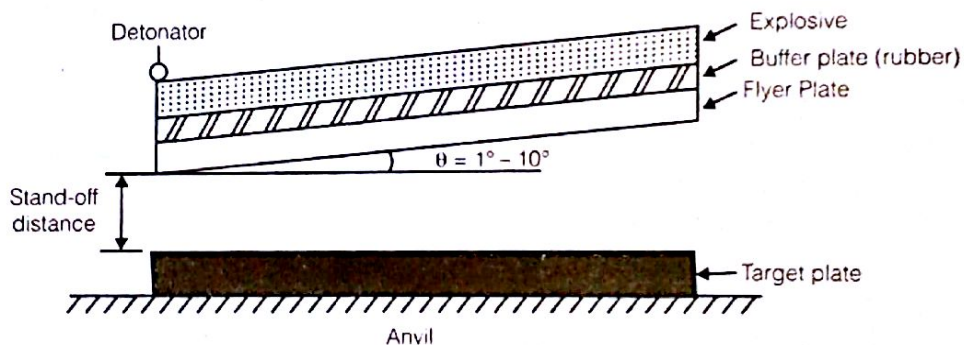


Fig. 6.36 : Schematic of Explosive welding

The impact velocity depends on the ratio of the explosive to that of the weight of the flyer plate and also on the contact angle. The maximum velocity can be decided by the sound in the target plate material because at supersonic velocities the wave in the target cannot propagate ahead of the bonding front. Minimum velocity is decided by magnitude at which the projected material becomes sufficiently plastic on impact to form a divided jet. The application of this process is in tube to tube sheet joints in heat exchangers, weld to pipe joints, blocking of leaking tubes in boilers, also when two plates are to be joined along the surface etc. This is also used for cladding a plate or slab with dissimilar metal.

6.7 RADIANT ENERGY WELDING

6.7.1 Electron Beam Welding

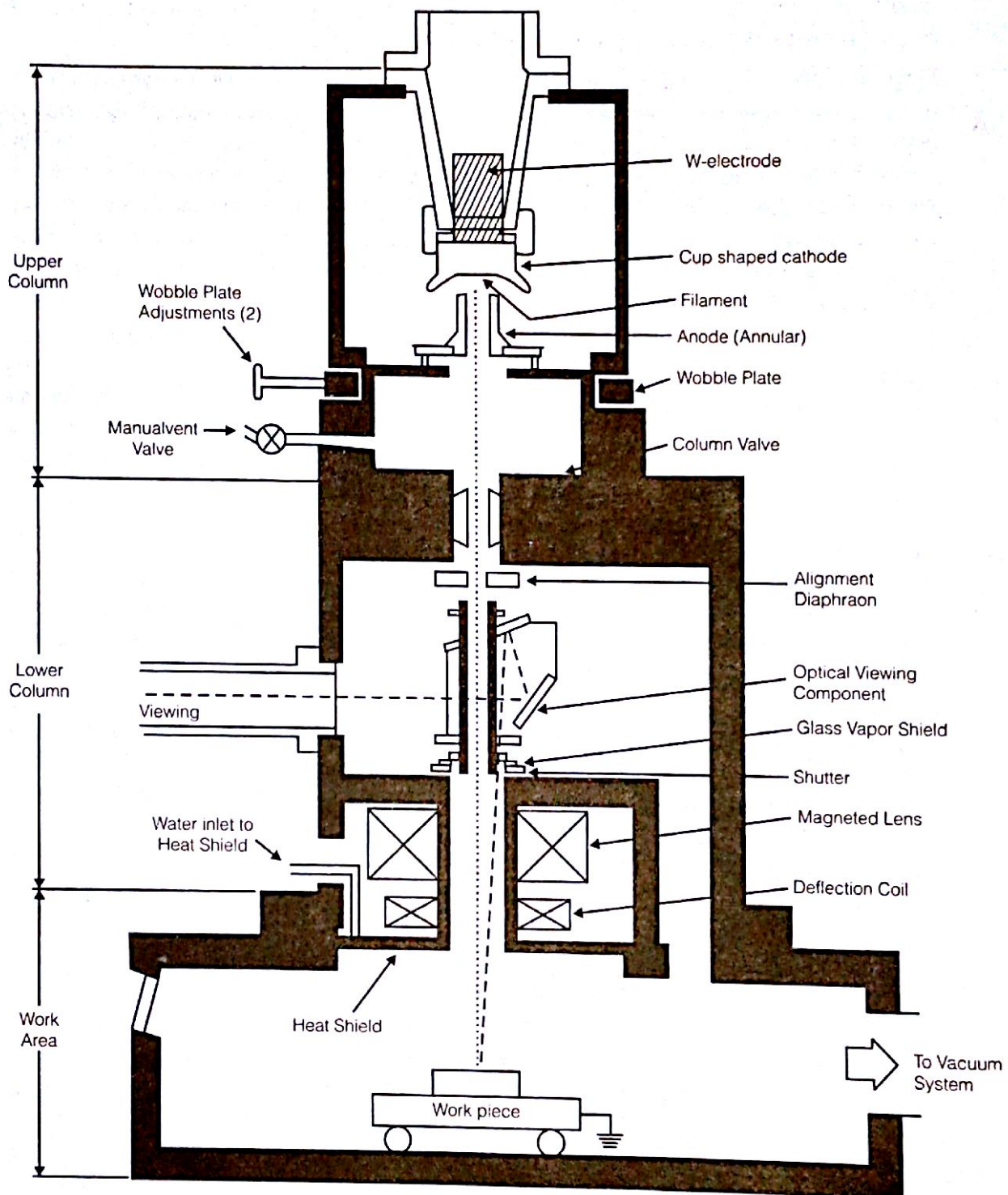


Fig. 6.37 : Electron Beam Welding

In electron beam welding a beam of electrons is used to melt the metal where it has to be welded. Electrons are generated with the help of tungsten electrode and cup shaped cathode directs the

electron towards annular anode. Since there are holes in anode, major portion of electrons will come on the other side. These electrons are converged to beam by creating magnetic field with the help of field electrodes. This electron beam has highly concentrated energy and can melt the metal within no time. Work piece experiences deep penetration and very insignificant heat affected zone. This phenomenon is called Key Hole phenomena.

Entire assembly is kept inside a chamber and vacuum is maintained in it. It is because high energy electrons will collide with air particles, particles will ionize and electrons will lose all their energy. As high energy electrons hit the work piece material, X- Rays will be produced, so inside surface of the container is lead lined. To make the electrons move uninterrupted it is essential to use the vacuum throughout the EBW gun column and the chamber. The electron beam is required to reach the work piece placed in the welding chamber to affect the necessary welding. If the electrons are projected into the normal atmosphere they lose all their kinetic energy in collision with atoms and molecules of oxygen and nitrogen.

Depending on the accelerating voltage the EBW guns are rated as low voltage and high voltage types with the range of voltages between 15-30 kv and 150kv respectively. This process is widely used in space industries, nuclear missile, air craft industries, cluster gears welding, intricate valve arrangements made of corrosion resistant alloys for automotive industries as well as in pressure capsules. The process produces very deep penetration and almost ideal weld is achieved. Other major applications are in welding Ti, Be, stainless steels, super alloys etc.

6.7.2 Laser Beam Welding

In laser welding a concentrated coherent light beam impinges at the desired spot to melt and weld the metal. Atoms from the ground level are pumped to high energy level with the help of primarily Xenon lamp. From the high energy level atom comes automatically to metastable state and once there is sufficient population inversion, atoms come to the ground level by emitting a bundle of energy called photon. These photons will be directed back and forth in the lasing tube. 98% reflecting lens means photons will not be allowed to come out, unless they are horizontal. Laser beam can be converged to a point. Laser emission is obtained when the upper level is sufficiently populated at the expense of lower level. Such a state is known as population inversion and the method obtained is called pumping. Laser beam welding is more versatile than the electron beam welding because welding is possible in air, through a transparent medium and along a profile.

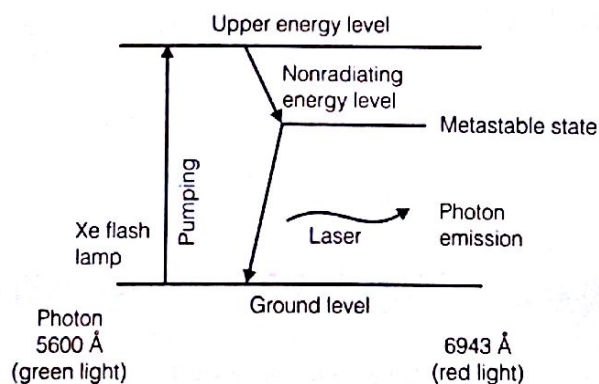


Fig. 6.38 : (a) Principle of laser emission

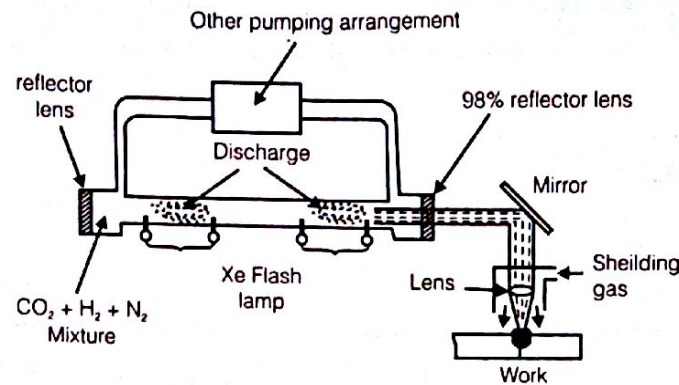


Fig. 6.38 : (b) Set up of CO₂ Laser beam welding

The most useful laser for welding is the laser in which the lasing medium is mixture of CO₂, nitrogen, and helium in the ratio of 1: 1: 10 at a pressure of 20 to 50mm of mercury. A laser consists of a glass tube in which the lasing gas mixture flows. There is one electrode at each of the two ends between which a high voltage discharge is set up. There is one reflector at each of the ends. The space between the two reflectors is called laser cavity. The laser beam emitted through the semi reflecting surface is focused to the desired spot. For industrial purposes the lasing material often used is ruby. Ruby is aluminium oxide with chromium atoms to the extent of 0.05%. The application of this is in radio engineering, electronics, welding copper and Aluminium alloys etc.

6.8 THERMIT WELDING PROCESS



(Ratio of Al and Fe according to atomic weight is 1:3)

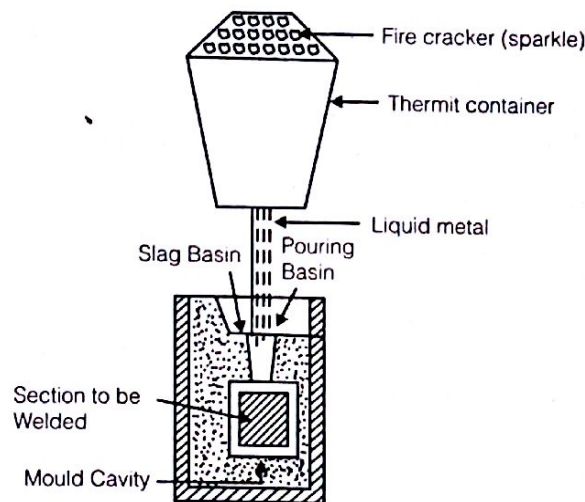


Fig. 6.39 : Thermit Welding process

Thermit is a mixture of aluminium powder and metal oxide. If this mixture is placed in a crucible and ignited by means of a fire cracker, the action once started continues throughout the mass of the mixture, giving out great heat because reaction is exothermic. The aluminium is a strong reducing agent, and combines with the oxygen from the iron oxide, the iron oxide being reduced to iron and intense heat will be released. The aluminium oxide floats to the top of the molten metal

as a slag which are contained in the mould. The high temperature of the iron results in excellent fusion taking place with the parts to be welded. A small percentage of additions like manganese or other alloying elements is done to increase the strength of joint.

Thermit welding involves aligning the parts to be joined, but with a gap between them is usually filled with wax, around which a sand or ceramic mold is built. If the parts are thick the mold cavity may be preheated to improve welding and dry the mold. Drying the mould is very important; otherwise superheated steam trapped in the mold can cause explosions. This process is used for joining tracks on site. This is also used in welding cable conductors, reinforcing bars and for heavy repairs such as those of broken necks and ship sterns.

6.9 ALLIED PROCESSES

If the parent material cannot withstand high temperature, or the parts to be joined are delicate or intricate or metals with different properties, thickness etc. then to weld with those processes is difficult, so to weld those, allied processes are introduced. In this additional metal is deposited on a substrate either by spraying or by some welding process are used :

There are three types of allied process

1. Soldering (flux is ZnCl_2)
2. Brazing (flux is Borax)
3. Adhesive bonding (Thermosetting plastic)

Soldering : The two surfaces are cleaned and a flux is applied over them. This flux dissolves whatever amount of oxide is remaining on the surface and also protects the surface from further oxidation. After the application of the flux the pieces are heated and the solder is then applied on the gap. The material flows into the interface of mating surface by capillary action. On cooling, it solidifies and provides a joint of adequate strength. Soldering is done by thoroughly cleaning the pieces with the help of wire brush, emery cloth, file or even steel wool. On cooling, the joint is cleaned by hot water to avoid corrosive action of the flux residue. Soldering of lead pipe is known as **wiping**.

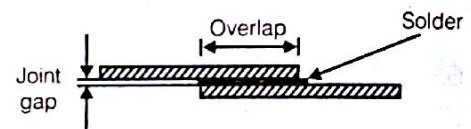


Fig. 6.40 : Soldering process

Soldering is used extensively in the electronics industry. Solders are not used for load bearing members because of the low strength than brazing. This process is used to join Copper with such precious metals such as silver and gold.

Brazing : The process is performed above 450°C but below solidus temperature of the base metal. The surfaces to be joined are grinded and then cleaned by applying some chemicals like Carbon Tetrachloride. A brazing flux (borex) is then applied over the surface to dissolve any remaining metal oxide. A brazing material like brass is poured at the joint. The molten metal fills by capillary action. Upon cooling and solidification of the filler metal, a strong joint is obtained. Joints to be brazed are made with small clearance, so that brazing flux is applied, to dissolve solid metal oxide which is still present and to prevent further oxidation. Brazing fluxes are generally borax, boric acid, borates, fluorides and chlorides. Surfaces to be brazed must be clean in order to obtain proper wetting and spreading characteristics of the molten filler metal in the joint and to develop maximum bond strength. Residual flux left on the brazed joint can be removed by washing with hot water followed by air drying. It is used to braze dissimilar metals with good joint strength. Intricate, light weight shapes can be joined rapidly and with little distortion. Brazing can be automated and used for mass production.

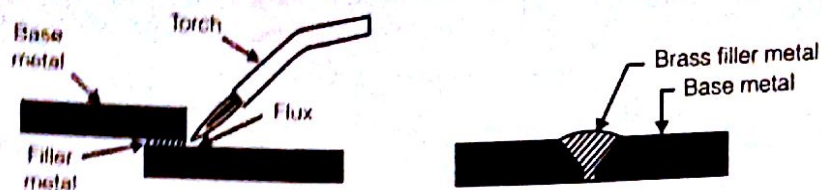


Fig. 6.41 : Brazing process

Adhesive bonding : In adhesive bonding a metal is joined to another metal or non metal by the use of an adhesive which consists of the thermosetting type. The pieces to be joined are thoroughly cleaned by chemicals or by mechanical means. Adhesives are applied to the cleaned surfaces by brushing, spraying, roller coating or dipping. The layer of adhesive applied depends upon the metal being bonded, type of adhesive, solvent used and the strength aimed. There is no metallic bond, but the bond is created by chemical action between the adhesive and metal being joined. The surface, before applying adhesive is degreased and suitably roughened. Usually the adhesive is applied in a liquid solvent and light pressure applied and joint heated to about for an half an hour for curing. Adhesive joints can be made to resist water or gas pressure and adhesive bonds have high damping capacity and thus high fatigue resistance.

This is used in manufacturing of railway cars, microwave reflectors, refrigerators, and storage tanks. This is also used in processes which include fastening of stiffeners to aircraft skin, attaching to brake shoes and joints in the aircraft wing and tail assemblies.

Surfacing : Due to continuous use of rolls in the rolling mill, rolls get eroded and since these are very expensive, it is repaired either by surfacing or cladding. In surfacing the material is liquified and with the help of compressed natural gases, liquified metal is sprayed over the rolls so that desired properties can be achieved, which include corrosion resistance, wear resistance, dimension control and metallurgical needs.

Different types of surfacing are : Cladding, Hardfacing, Buildup, and Buttering. In Cladding operation, electrode is in the form of thin sheet and with the help of submerged arc welding and gas arc welding it is coated over the rolls. In Hardfacing a metal is deposited over another surface to increase the hardness of another surface and to make it resistant to abrasion, impact, erosion, galling and cavitation. Abrasion resistance is the most important application in hardfacing. Buildup overlay is the rebuilding of worn out parts to restore them to original shape and dimensions. Buttering is the process of depositing one or more layers of a material between those metallurgically non-compatible materials which individually have compatibility with the material forming the buttering layer.

6.10 GAS WELDING

Oxygen cylinder valves are made of Brass and Acetylene cylinder valves are made by Steel. Brass valve does not corrode so easily and that is why brass valves are used in oxygen cylinder. Acetylene is a very dangerous gas because it can explode under its own weight. So calcium silicate is filled in the cylinder and then acetone is poured. Acetylene is absorbed in acetone. The absorbing capacity of acetone increases by increasing pressure. So the pressure of acetylene cylinder is higher. Only stainless steel valves will be used in acetylene cylinders because acetylene by reacting with copper produces copper acetylene which is an explosive.

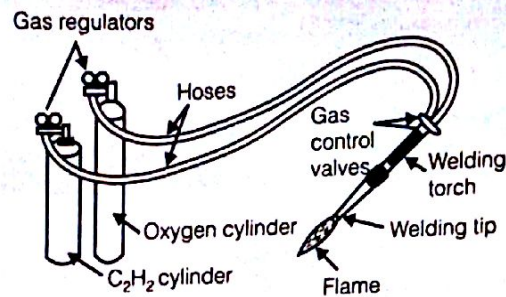


Fig. 6.42 : (a) Basic equipment used in oxyfuel gas welding.

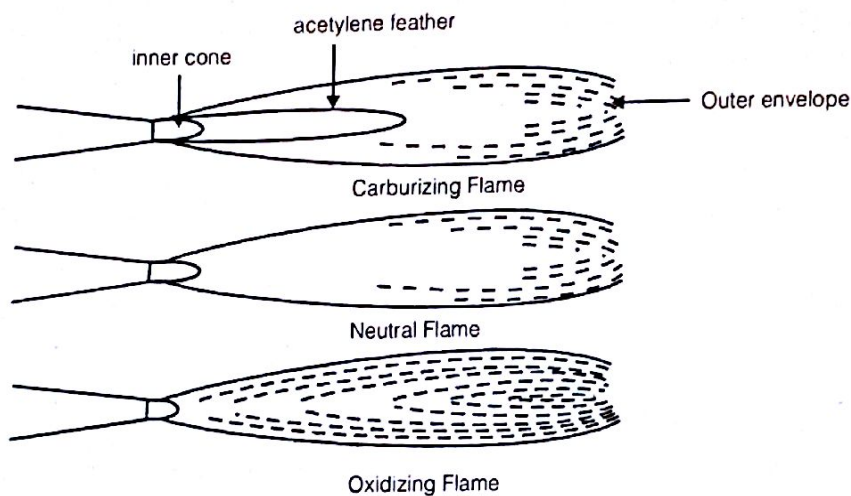


Fig. 6.42 : (b) Different types of flames

carburizing flames contains unburnt Carbon and after solidification of weld the bead will have pitted surface over it and the weld bead appear to be very hard and brittle, because lot of free Carbon will be present in the flame and it is used to weld high Carbon steels and cast Irons. It will not produce any sound. Because it contains unburnt carbon its temperature is lower than a neutral or an oxidizing flame. If the excess unburnt Carbon finds its way to the molten metal the weld puddle appears to be boiling.

Neutral flame produces hissing sound and the flame is used to weld low Carbon steels and Aluminium. This consists of nearly one to one ratio of acetylene and oxygen by volume. It consists of two parts namely the inner cone and the outer envelope. It has the clear luminous hissing cone indicating that the combustion is complete. Such a flame makes the hissing sound and it is useful to weld metals. The temperature of neutral flame is 3150°C .

Oxidized flames are the hottest flames and it produces roaring sound. This flame has an excess of oxygen over the acetylene. It consists of a very short pointed white inner cone and a shorter outer envelope. The reduction of length of the inner cone is a measure of excess oxygen. This is the hottest flame produced. These flames are used to weld alloys of Copper and Zinc. In welding these metals, the oxidizing flame produces a base metal oxide layer to protect the evaporation of low point alloying elements. The temperature of these flames is around 3480°C .

The welding procedures requires the ignition of oxy-acetylene flame and the manipulation of the torch to move the flame in the desired movement to get the required weld.

A welding flux is required to remove the oxide film and to maintain a clean surface. The flux melts at the melting point of the base metal and provides a protective layer against reaction with the atmospheric gases.

Thickness of plate

$t \leq 1 \text{ mm}$	$\theta = 20^\circ$
$= 1-3 \text{ mm}$	$\theta = 30^\circ$
$= 3-5 \text{ mm}$	$\theta = 40^\circ$
$= 5-7 \text{ mm}$	$\theta = 50^\circ$
$= 7-10 \text{ mm}$	$\theta = 60^\circ$
$= 10-15 \text{ mm}$	$\theta = 70^\circ$
$> 15 \text{ mm}$	$\theta = 80^\circ-90^\circ$

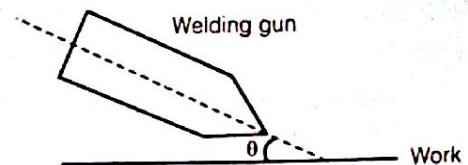


Fig. 6.42 : (c) Representing tip angle

In forehand welding the filler is held ahead of the flame while in backhand welding it follows it. Forehand welding ensures the uniform heating of the edges and better mixing of the metal in the weld pool. Both filler rod and flame are moved in weaving patterns. To weld material thicker than 5mm backhand welding is used. In this, flame heats the already deposited metal and that serves to heat treat both the weld metal and the heat affected zone.

Gas cutting :

Iron is heated on one of its side to a kindling temperature (it is the temperature at which rapid oxidation of material takes place). Cutting torch is moved and the flow of oxygen is suddenly increased in the desired direction. The melting point of iron oxide is much lower than iron. So gas cutting is an oxidation process not a melting process. Aluminium can not be cut by this process. Steel can be cut by this process. To cut any metal the following conditions have to be full filled

1. The kindling temperature should be lower than the melting temperature of the metal
2. The melting point of the parent metal should have higher temperature than the metal oxide which is formed by reaction with oxygen and it should be fluid in molten state so as to blow out easily.
3. It should have low thermal conductivity so that the material can be rapidly raised to its kindling temperature.

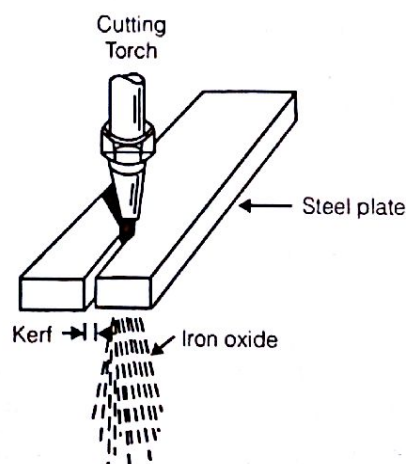


Fig. 6.43 : Flame cutting of steel plate with oxyacetylene torch

6.11 FORCES IN WELDING

The modes of the metal transfer which is operative at an intense during welding is dependent upon the cumulative effect of the different forces acting on the molten droplet growing at the tip of the electrode. The individual role of each force may vary. Some forces help in detaching the molten droplet while others help in retaining it at the electrode tip.

Gravity : This force will try to detach the molten droplet from the tip of the electrode and attach to the work piece. But in case of over head welding it is an attaching force. Numerically it is equal to the weight of the detaching droplet.

$$F_g = mg$$

Surface Tension : What ever is the welding position surface tension is an attaching force.

Drag : In gas welding drag force will appear due to flow of inert gases and it is always detaching force.

Electromagnetic pinch force or Lorentz force : Electrode can be considered as a number of parallel conductors and when the current flows in same direction an attractive force will develop. This will try to detach the molten droplets from the tip of electrode. In over head welding current settings has to be higher. Larger the current settings finer will be droplet size of liquid metal and higher will be the pinch force. This is required to move the liquid metal against gravity. Also in overhead welding work should be given +ve polarity to minimize dilution.

$$\text{Electromagnetic pinch force} \propto \frac{I^2}{200}$$

6.12 TYPES OF METAL TRANSFER

Short circuit transfer : In short circuit there is a periodic bridging of electrode and molten pool resulting in arc getting extinguished. Consequently heavy flow of current occurs which results in increased heating of the bridge. Decreased viscosity and surface tension, increased electromotive and hydrodynamic forces result in the transfer of molten metal from the electrode to the weld pool. With this the bridge breaks and the voltage jumps to open circuit voltage and the arc is reignited.

Dip transfer : This is also a short circuit mode of metal transfer but in this the electrode is fed into the weld pool at a fast pace so that the electrode is dipped into the molten metal before droplet is detached. Dip transfer also appears in electroslag welding. Due to lower temperature of molten pool there are high chances of slag inclusion.

Globular Metal Transfer : When the current settings are slightly higher molten droplet size increases and the detachment primarily takes place by gravity and groove will be filled drop by drop as a result of that bead density will be low. The detached globule travels under the action of gravity and hydrodynamic forces directly towards the weld pool and is referred to as drop transfer. This type of transfer encountered where the arc length is medium to long. The droplet temperature is also higher than in the case of short – circuit transfer.

Spray Transfer : This type of transfer takes place at higher current settings which results in bead structure. As the current density is raised the droplet growth rate increases proportionately to the increase in temperature and electromagnetic forces in the form of pinch effect become significant. Droplets are pinched off before they attain the size permitted by the surface tension and that results in spray mode transfer. Drop spray is found to give least spatter and smoke with higher deposition efficiency than other variants of spray modes. Spray mode transfer is associated with GMAW with medium to long lengths.

Repelled Transfer : In D.C arc welding because of fixed polarity magnetic lines setup in the work piece and the tendency of arc is to be deflected towards the magnetic lines, the welding process

will have lot of spatter. In case of arc blow metal deviate from its intended path and produces severe and pattern called repelled transfer. To avoid this problem of arc blow metal pieces are kept at the entry and exit called tab ins and tab outs. So while performing welding at the ends magnetic lines will continue in this material and there will not be any arc blow. This mode of transfer is usually encountered in welding of steel with medium arc length and low medium welding current.

Explosive Transfer : Sometimes the droplet is shattered either while it is still at the electrode tip or soon after detachment. This type of metal transfer is known as explosive transfer and is attributed to the formation of gas bubbles within the liquid drop at the electrode tip. The bubbles are due to the formation of CO in the case of steels and some absorbed gases in the case of non – ferrous metals.

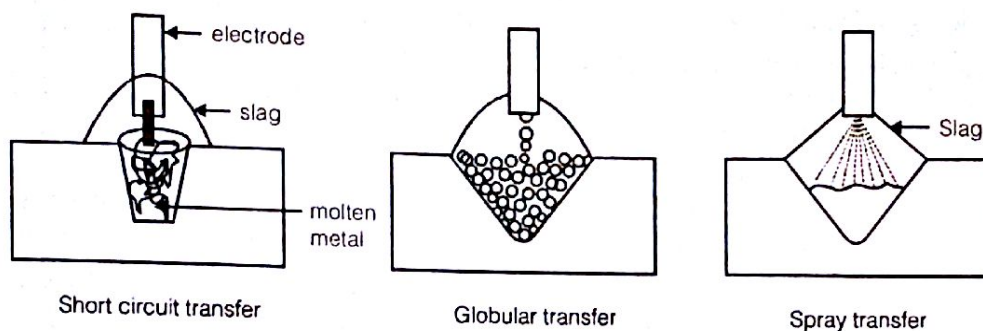


Fig. 6.44 : Different types of metal transfer

6.13 TYPES OF FLUXES

1. Cellulose : The mixture contains

- 20 - 60% TiO_2
- 10 - 20% cellulose
- 15 - 30% quartz
- 3 - 100 ppm is H_2
- 0 - 15% carbonates
- 5 - 10% ferromanganese

These fluxes are having high hydrogen content and by reaction it produces H_2 gas and it is exothermic reaction. Thus deeper penetration will be produced but as the gas is coming out it leaves either large number of fine holes or some time cracks called hydrogen embrittlement. The metal deposited by electrodes with these coatings is fine grained and contains hardly any oxygen. These coatings are used for positional welding, particularly where a good degree of penetration is required.

2. Rutile :

- 40 - 60% Natural TiO_2
- 15 - 30 ppm hydrogen
- 10 - 14% Thermomanganese
- 0 - 5% Organic cellulose
- 15 - 20% Quartz
- 0 - 15% Carbonates

Rutiles are characterized by heavy alloy content due to which it produces thick coating of slag over it. These are also called general purpose electrodes. These electrodes give medium penetration welds of good appearance with very high mechanical properties. Advantage is for high arc stability and positional welding properties. Most of the general purpose coated electrodes used for welding low carbon structural steels are of this type.

3. **Acidic coating** : The mixture contains Fe_3O_4 , MnO_2 , Quartz, Silicates, Carbonates, Ferromanganese and very high hydrogen content.

The slag produced have acid reaction and thus, dissolve basic oxide like MnO , consequently a large amount of manganese is transferred to the also. The manganese present in the slag lowers the viscosity, which tends to improve the appearance of the weld bead and makes it possible to deposit weld metal in all positions.

4. **Basic coatings** : The mixture contains

40 - 50% CaCO_3
 20 - 40% Fluorspar and feld spar
 0 - 5% quartz
 0 - 10% Rutile
 5 - 10% Ferroalloys

Although it is easy to weld by basic coated electrodes but due to the presence of CaCO_3 , flux is having a tendency to capture moisture from the surrounding. So the electrode has to be baked in an oven before use and it has to be consumed as fast as possible. In these coatings there is no use of minerals which combine with water. This ensures lowest possible content of hydrogen in the weld metal. That is why they are also known as low - hydrogen electrodes. The hydrogen electrodes have superior weld properties with highest ductility of any of the weld deposits. The welds are therefore resistant to cracking.

6.14 ISO DESIGNATION

Basis for coding :

1. A prefix letter.
2. Letters to denote the type of covering.
3. A code number of four digits.
4. In some case a suffix, consisting of one or more letters, to indicate special characteristics.

Example representation can be shown as,

ER 4312 H J X

1. Here E = extrusion is used to make the electrode
2. R = Type of flux used
 A - Acidic
 B - Basic.
 R - Rutile.
 C - Cellulose.
3. In code number the first two digits give the mechanical properties of the weld deposit and last two digits give the performance characteristics of the coverings.
 4 and 3 are mechanical properties of the joint
 4-Yield strength and ultimate tensile strength
 3-% of elongation.
 1-Welding position.

- 2-Welding current and voltage settings.
 4. H - Hydrogen Controlled electrode.
 J-Iron powdered electrode.
 X-Radio graphic quality of weld.

6.15 WELDING POSITIONS

The angle which the weld root makes with the horizontal is called weld slope and by drawing normal over the bead the angle this line makes with the vertical is called weld rotation.

Weld position	Symbol	Slope	Rotation
Flat	F	0 - 5°	0 - 10°
Horizontal	H	0 - 5°	30 - 90°
Vertical	V	80 - 90°	0 - 180°
Down head	D	80 - 90°	0 - 180°
Over head	O	0 - 15°	115 - 180°

6.16 TYPES OF JOINTS

- Butt joint** : Butt weld can be formed by welding plates end to end. The angle will be 135°-180°
- Lap joint** : A lap joint is the one in which plates overlap each other. The angle will be 0°-5°
- T-joint** : The angle of T-joint is 5°-90°.
- Edge joint** : The angle of edge joint is 30°-135°
- Corner joint** : The angle is 5°-30°
- Cruciform joint** :

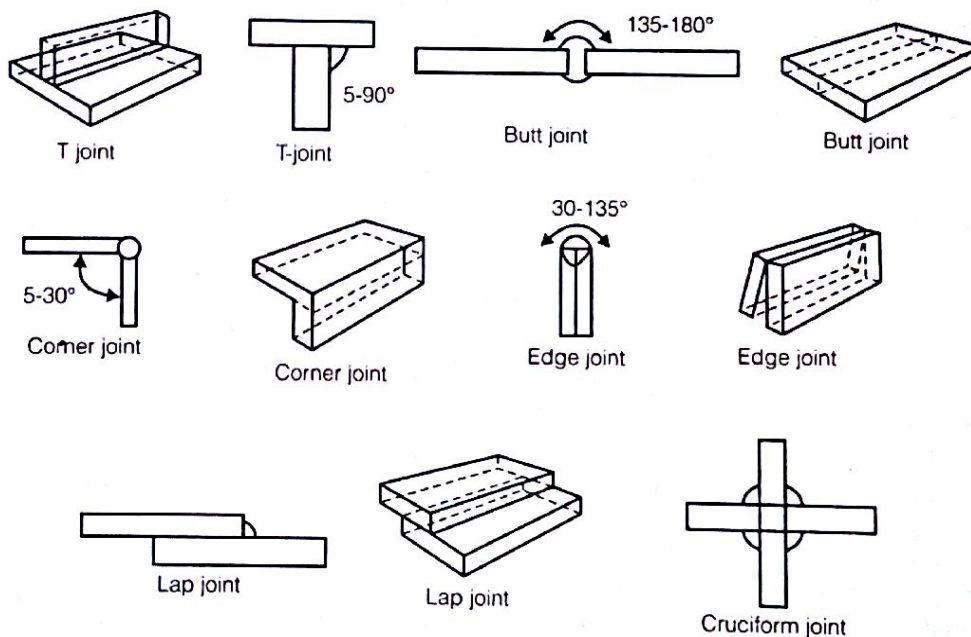


Fig. 6.45 : Different types of welds

These are type of joints which can be prepared through different welding processes. Joints are prepared with an incident angle with root face and root gap as required for the plate thickness. The plates can be tack welded in position to prevent movement due to expansion and contraction during welding and tack welds must be strong enough to prevent movement of the plates.

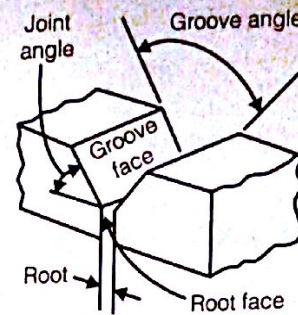


Fig. 6.46 : Nomenclature for edge preparation

6.17 TYPES OF WELD

1. Fillet weld
2. Groove weld
3. Spot
4. Seam
5. Surfacing
6. Plug.

The root gap is provided to achieve full penetration while root face avoids burn-through due to excessive heat concentration at sharp edges. The groove angle is dependent upon proper fusion of the sides with the weld metal from the electrode.

Fillet weld :

$$A = l \cos 45^\circ \times W$$

It always fails in the minimum cross section, due to shear.

So

$$\text{force} = K' \times A$$

$$K' = \text{Yield strength in shear}$$

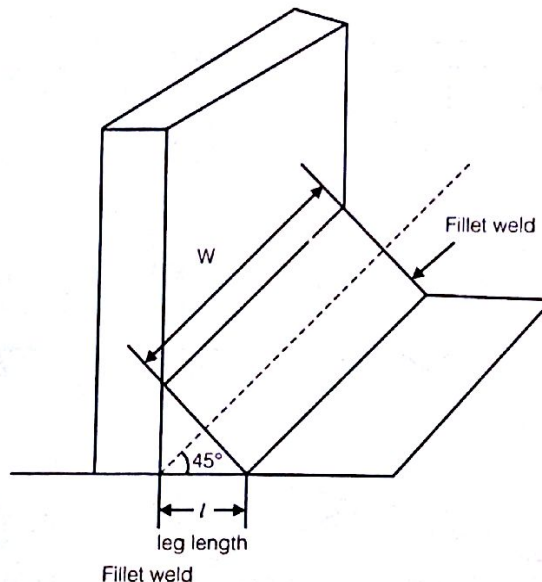


Fig. 6.47

Using intense source of heat energy or by giving work piece positive polarity of penetration extends in another work material, after solidification there will be a joint between the two materials. This is called plug weld.

6.18 WELDING SYMBOLS

Some welding symbols are represented as below.

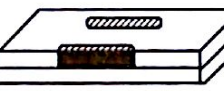
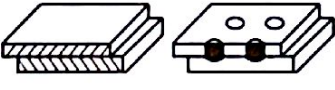
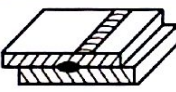
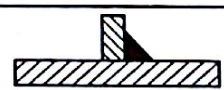
DESCRIPTION	SECTIONAL REPRESENTATION	SYMBOL
1. Butt weld between flanged plates (flanges melted down completely)		
2. Square butt weld		
3. Single-V butt weld		
4. Single-bevel butt weld		
5. Single-V butt weld with broad Root face		
6. Single-bevel butt weld with broad Root face		
7. Single butt weld		
8. Single-J butt weld		
9. Backing or sealing run		
10. Fillet weld		
11. Plug weld (circular or Elongated hole, Completely Filled)		
12. Spot weld (resistance or Arc welding or projection weld)		
13. Seam weld		
14. Flat (flush) single-V butt weld		
15. Convex double-V butt weld		
16. Concave fillet weld		
17. Flat (flush) single-V butt weld with flat (flush) backing run		

Fig. 6.48 : Representation of welding symbols and supplementary welding symbols.

Representation of the weld :

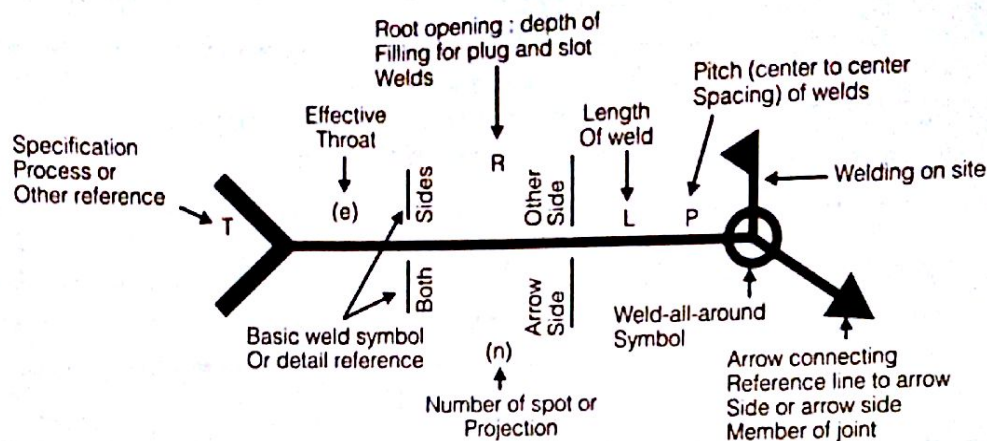


Fig. 6.49 : (a) Various representations of symbols.

Information below the line refers to the same side of arrow and information above the line refers to the opposite side. Flag indicates that welding is performed on sight. Initially there was a V-groove, but there was some defect in the bead. So the deposited material was removed (Back Gouging) and V was prepared on the other side. To minimize the distortion sealing run was performed and its reinforcement was grinded and the process was performed using GTAW process on sight.

6.19 DEFECTS IN WELDING

The ideal weld should be such that adequate fusion exists between the filler metal and edge preparation together with good penetration. The major discontinuities are

1. **Porosity :** Porosity is caused due by the entrapment of gas bubbles by the freezing dendrites during the cooling of the weld pool and occur essentially only in the weld metal, or by chemical reactions during welding, or by contaminants. These are generally in the shape of spheres or of elongated pockets. The porosity may be distributed through out weld zone, or may be concentrated in a certain region. This can be reduced by proper selection of filler metals, by preheating the weld area, by proper cleaning the weld zone, and by reducing the welding speeds.
2. **Slag inclusions:** Inclusions may be caused by compounds such as oxides, fluxes, and electrode coating materials, which are trapped in the weld zone. If shielding is not provided properly the contaminants from atmosphere will contribute to such inclusions. This can be reduced by cleaning the weld bead, by providing enough shielding gas.
3. **Incomplete fusion and penetration :** It is usually caused by insufficient heat and too fast travel of torch or electrode. This can be avoided by raising the temperature of the base metal, cleaning the weld area, providing enough shielding gas. Incomplete penetration occurs when the depth of the welded joint is insufficient. This can be reduced by increasing the heat input, reducing the speed, changing joint design and ensuring proper fit.

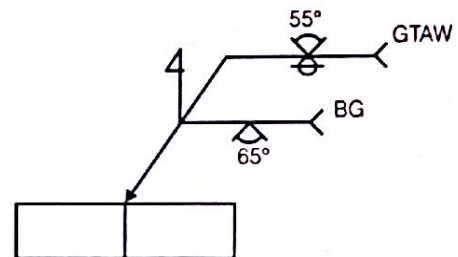


Fig. 6.49 : (b)

4. **Under cutting :** It is the melting or burning away the base metal at the toe of the weld as sharp recess or notch. Undercut can be as stress raiser and can reduce the fatigue strength of the joint. In such cases it may lead to premature failure. These undercuts are generally due to excessive weaving speeds.
5. **Under filling:** It results when the joint is not filled with the proper amount of the weld metal.
6. **Incomplete fusion :** This is because of failure in fusing adjacent layers of weld metal together. This is caused by failure to raise the temperature of base metal to its melting point or failure to remove oxides or other foreign material.
7. **Overlapping :** it is the protrusion of weld metal beyond the root of the weld and occurs due to insufficient travel speed which permits the weld puddle to move ahead of electrode, also due to insufficient angle.

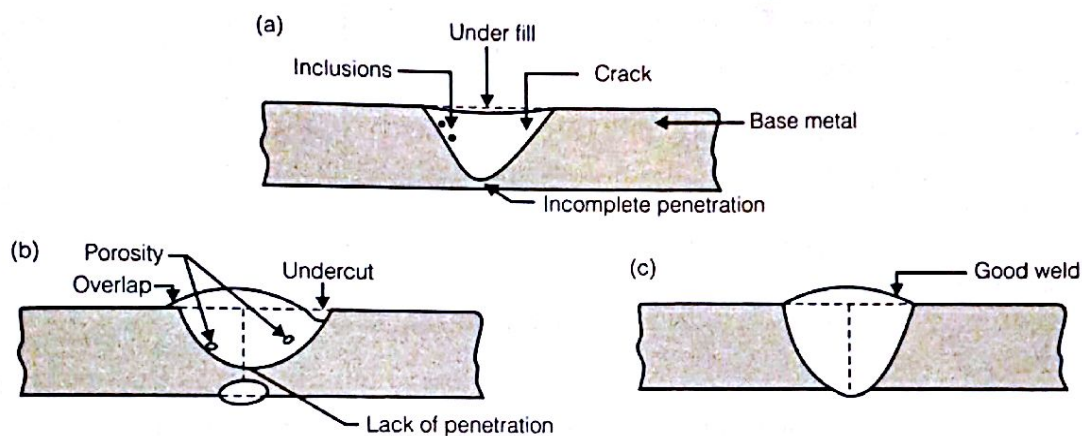


Fig. 6.50 : (a) Different welding defects

8. **Cracks :** Cracking is the most serious defect in a weld since it can lead to premature failure particularly in a dynamically loaded component. The typical types of cracks are longitudinal, transverse, crater, underbead and toe cracks. Cracks occurs due to; temperature gradients that causes thermal stresses in weld zone, variations in the compositions of the weld zone, hydrogen embrittlement, inability of the weld metal to contract during cooling and embrittlement of grain boundaries.

There are two types of cracks, hot crack and cold crack. Hot cracks occur while the joint is still at elevated temperatures. Cold cracks develop after the weld metal has solidified.

This can be prevented by changing the joint design, by changing the parameters, procedures and the sequence of the welding process, preheating the component, and by avoiding rapid cooling of the weld components.

9. **Lamellar tears :** The work piece when tested at its thickness direction it is weaker alignment of nonmetallic impurities and inclusions. This is mainly in rolled plates. In welding such components these lamellar tears will appear, because of shrinkage of the restrained components during cooling. This can be avoided by providing for shrinkage of the members.

10. **Surface damage :** This occurs due to spatter during the welding. Because of that small droplet of metal deposited on adjacent surfaces. Such surface discontinuities are objectionable. By using proper welding techniques and procedures surface damage can be avoided.
11. **Stresses and Distortion in welding :** In the welding process we have a molten pool of metal which consists partly of the parent metal melted or fused from the side of the joint, and partly of the electrode or filler rod. As welding proceeds this pool travels along and heat is lost by conduction and radiation resulting in cooling of the joint. The cooling takes place with varying rapidity depending on many factors such as size of work, quality of weld metal being deposited, thermal conductivity of the parent metal and the melting point and specific heat of the weld metal.

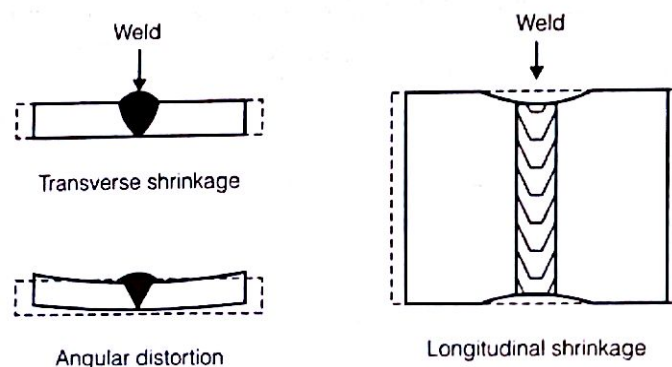


Fig. 6.50 : (b) Distortion of parts after welding

As the weld proceeds there are areas surrounding the weld in varying conditions of expansion and contraction, and thus a varying set of forces will be set up in the welded parent metal. When the weld has cooled, these forces still remain, they are called residual stresses and they are not due to any external load but due to internal forces. These stresses cause elastic and plastic deformation. The process of removal of these residual stresses is called stress relieving.

Stresses are set up during manufacturing due to rolling and forging. Some of these stresses will be relieved during welding because of heating and because of that distortion reduces. If the welded plates are free to move distortion occurs and if the plates are rigid the stresses remain as residual stresses.

Depositing the weld metal with slightly higher current, gives wider and deeper layer. On cooling the plate distorts and bends in upward direction with the weld on the inside of the bend. If the quantity of heat supplied is small, the contraction forces will be small and no distortion occurs. But because of the higher heat higher temperature will be set up on the upper side of the plate, therefore the upper side contracts more than the lower side and due to the pull of the contracting line of the weld metal distortion occurred. An increase in the weld speed, distortion also increases and greater the number of layers of weld metal deposited, the greater will be the distortion.

Distortion is reduced by step welding. In this the line of weld is broken up into short lengths, each length is ending where the other began. By this the expansion and contraction area next to each other neutralizes.

Peening is the processes of lightly hammering the weld and the surrounding parent metal in order to relieve stresses present and to consolidate the structure of the weld metal. It may be carried out while the weld is still hot or immediately the weld has cooled.

Preheating and post heating is done to reduce the internal stresses and also to harden the areas in the HAZ. To minimize angular distortion very small amount of material is deposited on the opposite face called sealing run. It also closes the root gap. The reinforcement of the sealing run is undesirable. So it has to be grinded. This is called dressed flush.

In electroslog or electrogas welding when temperature of molten pool is not controlled, the thick plates will bend, which called rotational distortion. In welding cast iron, preheating must is necessary, otherwise because of lack of ductility it will easily fracture before it distort.

oooo

PRACTICE QUESTIONS

1. The correct sequence of the given materials in ascending order of their weldability is:
- | | |
|--------------------------------------|--------------------------------------|
| (a) Ms, copper, cast iron, aluminium | (b) Cast iron, Ms, aluminium |
| (c) Copper, cast iron, Ms, aluminium | (d) Aluminium, copper, cast iron, Ms |

2. Match the following:

Work material

- P. Aluminium
- Q. Die steel
- R. Copper wire
- S. Titanium sheet

Type of joining

- 1. Submerged arc welding
- 2. Soldering
- 3. Thermit welding
- 4. Atomic hydrogen welding
- 5. Gas tungsten arc welding
- 6. Laser beam welding

- (a) P-2, Q-5, R-1, S-3
- (c) P-4, Q-1, R-6, S-2

- (b) P-6, Q-3, R-4, S-4
- (d) P-5, Q-4, R-2, S-6

3. Consider the following statements:

The size of the heat affected zone will increase with:

- 1. increase starting temperature
- 2. increase welding speed
- 3. increase thermal conductivity of base metal
- 4. increase in base metal thickness

Which of the following given above are correct?

- | | |
|----------------|----------------|
| (a) 1, 2 and 4 | (b) 1, 2 and 3 |
| (c) 1 and 3 | (d) 2 and 3 |

4. Two plain carbon steel specimens having 0.8% carbon contents are welded. If we observe the weldment under Metallurgical Microscope from centre towards either side, the following structures are observed at different zones:

- 1. Fine pearlite
- 2. Coarse pearlite
- 3. Martensite

Select the correct answer using the codes given below:

- | | |
|-------------|-------------|
| (a) 1, 2, 3 | (b) 1, 3, 2 |
| (c) 2, 1, 3 | (d) 3, 1, 2 |

5. Fabrications weldability test is used to determine

- (a) Mechanical properties required for satisfactory performance of welded joint.
- (b) Susceptibility of welded joint for cracking
- (c) Suitability for joint design
- (d) Appropriate machining process

6. Which one of the following is not a fusion welding process.

- | | |
|-----------------|------------------------|
| (a) Gas welding | (b) Arc welding |
| (c) Brazing | (d) Resistance welding |

7. Consider the following statements:

Assertion(A): Aluminium has poor weldability

Reason(R): Aluminum has high thermal conductivity and high affinity to oxygen.

- (a) Both A and R are individually true and R is the correct explanation of A.
- (b) Both A and R are individually true but R is not the correct explanation of A.
- (c) A is true but R is false.
- (d) A is false but R is true.

8. Consider the following statements: MIG welding process uses

- 1. Consumable electrode
- 2. Non-consumable electrode
- 3. D.C power supply
- 4. A.C power supply

Of these statements:

- (a) 2 and 4 are correct
- (b) 2 and 3 are correct
- (c) 1 and 4 are correct
- (d) 1 and 3 are correct

9. Which of the following gases can be used for GMAW as a shielding gas?

- 1. Argon
- 2. Oxygen
- 3. Carbon dioxide

Select the correct answer using the code given below:

- (a) 1, 2 and 3
- (b) 1 and 2
- (c) 2 and 3
- (d) 1 and 3

10. Consider the following statements:

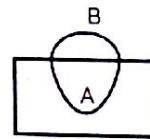
Assertion (A): The electrodes of ac arc welding are coated with sodium silicate, where as electrodes used for dc arc welding are coated with potassium silicate binders.

Reason (R): Potassium has a lower ionisation potential than sodium.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is not the correct explanation of A.
- (c) A is true but R is false
- (d) A is false but R is true.

11. An arc welded joint is shown in the figure. The part labeled 'B' in the figure is known as:

- (a) Weld preparation
- (b) Penetration
- (c) Reinforcement
- (d) Slag



12. In an arc welding process, the voltage and current are 25 V and 300 A respectively. The arc heat transfer efficiency is 0.85 and welding speed is 8 mm/sec. The net heat input (in J/mm) is.

- (a) 64
- (b) 797
- (c) 1103
- (d) 79700

13. The voltage-current characteristics of a DC generator for arc welding is a straight line between an open-circuit voltage of 80 V and short-circuit current of 300A. The generator settings for maximum arc power will be:

- (a) 80V and 150A
- (b) 40V and 300A
- (c) 40V and 150A
- (d) 80V and 300A

14. Which of the following statements is correct?

- (a) No flux is used in gas welding of mild steel
- (b) Borax is the commonly used flux coating on welding electrodes.

- (c) Laser beam welding employs a vacuum chamber and thus avoids use of a shielding method.
 (d) AC can be used for GTAW process
15. Arc blow is more common in
 (a) AC welding (b) DC welding with straight polarity
 (c) DC welding with bare electrodes (d) AC welding with bare electrodes
16. Pinch effect in welding is the result of
 (a) Expansion of gases in the arc
 (b) Electromagnetic forces
 (c) Electric force
 (d) Surface tension of the molten metal
17. In manual arc welding, the equipment should have drooping characteristics in order to maintain the
 (a) Voltage constant when arc length changes
 (b) Current constant when arc length changes
 (c) Temperature in the arc constant
 (d) Weld pool red-hot
18. In arc welding DC reverse polarity is used to bear greater advantage in
 (a) overhead welding (b) flat welding of lap joints
 (c) edge welding (d) flat welding of butt joints
19. Match **List-I** (Ingredients) with **List-II** (Welding functions) and select the correct answer using the codes given below the lists:

List-I

- A. Silica
 B. Potassium silicate
 C. Ferro silicon
 D. Cellulose

List-II

1. Arc stabilizer
 2. Deoxidizer
 3. Fluxing agent
 4. Gas forming material

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	2	1	3	4
(c)	3	1	2	4
(d)	2	4	3	1

20. Match **List-I** (Welding defects) with **List-II** (Causes) and select the correct answer using the Codes given below the lists:

List-I

- A. Spatter
 B. Distortion
 C. Slag inclusion
 D. Porosity

List-II

1. Damp electrodes
 2. Arc blow
 3. Improper cleaning in multipass welding
 4. Poor joint selection

Codes:

	A	B	C	D
(a)	4	2	3	1
(b)	4	2	1	3
(c)	2	4	1	3
(d)	2	4	3	1

21. In arc welding of a butt joint, the welding speed is to be selected such that highest cooling rate is achieved. Melting efficiency and heat transfer efficiency are 0.5 & 0.7, respectively. The area of the weld cross section is 5mm^2 and the unit energy required to melt the metal is 10 J/mm^3 . If the welding power is 2 kW , the welding speed in mm/s closest to
- (a) 4 (b) 14
(c) 24 (d) 34
22. Which of the following are the major characteristics of submerged arc welding?
1. High welding speeds
 2. High deposition rates
 3. Low penetration
 4. Low cleanliness
- Select the correct answer using the code given below:
- (a) 2 and 3 (b) 1, 2 and 3
(c) 3 and 4 (d) 1 and 2
23. Consider the following statements:
1. In arc welding, 65% to 75% heat is generated at the node.
 2. Duty cycle in case of arc welding is the cycle of complete welding of work piece from the beginning
 3. Arc blow is more common with DC welding
- Which of the statements given above are correct?
- (a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3
24. In MIG welding at high current, the metal is transferred into the form of which of the following?
- (a) A fine spray of metal (b) Molten drops
(c) Weld pool (d) Molecules
25. The coating material of an arc welding electrode contains which of the following
1. Deoxidizing agent
 2. Arc stabilizing agent
 3. Slag forming agent
- Select the correct answer using the code given below:
- (a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only
26. **Assertion(A):** Submerged arc welding is not recommended for high carbon steels, tool steels, aluminium, magnesium etc...
- Reason(R):** This is because of unavailability of suitable fluxes, reactivity at high temperatures and low sublimation temperatures.
- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true and R is not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
27. The maximum heat in resistance welding is at the :
- (a) tip of the positive electrode
(b) tip of the negative electrode
(c) top surface of the plate at the time of electric contact with the electrode
(d) interface between the two plates being joined

28. Two 1 mm thick steel sheets are to be spot welded at a current of 5000 A. Assuming effective resistance to be 200 micro-ohms and current flow time of 0.2 seconds, heat generated during the process will be
- (a) 0.2 Joules (b) 1 Joules
(c) 5 Joules (d) 1000 Joules
29. In resistance welding, heat is generated due to the resistance between
- (a) Electrode and work piece (b) Asperities between touching plates
(c) Two dissimilar metals being in contact (d) Inter atomic forces
30. Two metallic sheets, each of 2.0 mm thickness, are welded in a lap joint configuration by resistance spot welding at a welding current of 10 KA and welding time of 10 milliseconds. A spherical fusion zone extending up to the full thickness of each sheet is formed a properties of the metallic sheets are given as:
- ambient temperature = 233 K
melting temperature = 1793 K
density = 7000 kg/m³
specific heat = 800 J/kgK
latent heat of fusion = 300 kJ/kg
- Assume:**
1. contact resistance along sheet-interface is 500 micro-ohm and along electrode-sheet interface is zero.
 2. no conductive heat loss through the bulk sheet materials; and
 3. the complete weld fusion zone is at the melting temperature. The melting efficiency(in %) of the process is
- (a) 50.37 (b) 60.37
(c) 70.37 (d) 80.37
31. Spot welding of two 1mm thick sheets of steel (density = 8000 kg/m³) is carried out successfully by passing a certain amount of current for 0.1 second through the electrodes. The resultant weld nugget formed is 5mm in diameter and 1.5 mm thick. If the latent heat of fusion of steel is 1400 kJ/kg and the effective resistance in the welding operation is 200 ohms, the current passing through the electrodes is approximately
- (a) 1480 A (b) 3300 A
(c) 4060 A (d) 9400 A
32. Tool material not suited to resistance welding is
- (a) aluminium oxide (b) stellite
(c) high speed steel (d) masonite
33. In oxy-acetylene gas welding, for complete combustion, the volume of oxygen required per unit of acetylene is
- (a) 1 (b) 1.5
(c) 2 (d) 2.5
34. In gas welding of mild steel using an oxy-acetylene flame, the total amount of acetylene consumed was 10 liters. The oxygen consumption from the cylinder is
- (a) 5 liters (b) 10 liters
(c) 15 liters (d) 25 liters
35. In oxyacetylene gas welding, temperature at the inner cone of the neutral flame is around
- (a) 3500°C (b) 3200°C
(c) 2900°C (d) 2550°C

36. Oxyacetylene reducing flame is used while carrying out the welding on
 (a) mild steel (b) high carbon steel
 (c) grey cast iron (d) alloy steels
37. **Assertion(A):** If neutral flame is used in oxy-acetylene welding, both oxygen and acetylene cylinders of same capacity will be emptied at the same time.
Reason(R): Neutral flame uses equal amounts of oxygen and acetylene.
 (a) Both A and R are individually true and R is the correct explanation of A
 (b) Both A and R are individually true and R is not the correct explanation of A
 (c) A is true but R is false
 (d) A is false but R is true
38. Consider the following statements:
 1. In gas welding, the torch should be held at an angle of 30° to 45° from the horizontal plane
 2. In gas welding, the angle of the torch depends upon the thickness of metal to be formed.
 3. Drag in gas cutting is the time difference between heating of the plate and starting the oxygen gas for cutting.
 Which of the statements given above are correct
 (a) 1, 2 and 3 (b) 1 and 2
 (c) 2 and 3 (d) 1 and 3
39. Consider the following statements in respect of oxyacetylene welding
 1. The joint is not heated to a state of fusion
 2. No pressure is used
 3. Oxygen is stored in steel cylinder at a pressure of 14 MPa
 4. When there is an excess of acetylene used, there is a decided change in appearance of flame.
 Which of the statements given above are correct
 (a) 1, 2 and 3 (b) 2, 3 and 4
 (c) 1, 3 and 4 (d) 1, 2 and 4
40. The metal powder used in thermit welding of steel is
 (a) Al (b) Cu
 (c) Pb (d) W
41. In atomic hydrogen welding, hydrogen acts as
 (a) A heating agent
 (b) One of the gases to generate the flame
 (c) An effective shielding gas protecting the weld
 (d) A lubricant to increase the flow characteristics of weld metal
42. In which one of the following welding techniques is vacuum environments required?
 (a) Ultrasonic welding (b) Laser beam welding
 (c) Plasma arc welding (d) Electron beam welding
43. High speed electron beam welding is focused on the weld spot using:
 (a) Vacuum lens (b) Insert gas lens
 (c) Optical lens (d) Magnetic lens
44. Which one of the following welding processes consists of minimum heat affected zone(HAZ)?
 (a) Shielded Metal arc welding(SMAW) (b) Laser Beam Welding(LBW)
 (c) Ultrasonic Welding(USW) (d) Metal Inert Gas Welding(MIG)

45. Consider the following statements in respect of the laser beam welding:

1. It can be used for welding any metal or their combinations because of very high temperature of the focal points.
2. Heat affected zone is very large because of quick heating
3. High vacuum is required to carry the process

Which of the statements given below is/are correct?

- (a) 1 and 2 only (b) 2 and 3 only
(c) 1 only (d) 1, 2 and 3

46. In a fillet welded joint, the weakest area of the weld is:

- (a) toe (b) root
(c) throat (d) face

47. Match **List-I** (Filler rod materials) with **List-II** (Joining process) and select the correct answer using the codes given below the lists:

List-I

- A. Mild steel
B. Bronze
C. Brass
D. Lead and tin alloy

List-II

1. MIG welding
2. Soldering
3. Brazing
4. Thermit welding
5. Braze welding

Codes:

	A	B	C	D
(a)	1	5	3	2
(b)	4	3	2	5
(c)	4	3	5	2
(d)	1	3	5	4

48. The strength of a brazed joint

- (a) decreases with increase in gap between the joining surfaces
(b) increase with increase in gap between the two joining surfaces
(c) decreases up to certain gap between the two joining surfaces beyond which it increases
(d) increases up to certain gap between the two joining surfaces beyond which it decreases

49. Match the **List-I** (Welding problems) with **List-II** (Causes) and select the correct answers using the codes given below the lists:

List-I

- A. Cracking of base metal
B. Cracking of bead
C. Porosity
D. Inclusion

List-II

1. Excessive stress weld metal
2. High joint base metal rigidity
3. Failure to remove slag from previous deposit
4. Oxidation
5. Excessive hydrogen, oxygen, nitrogen in the welding atmosphere

Codes:

	A	B	C	D
(a)	2	1	5	3
(b)	3	4	2	1
(c)	2	4	5	3
(d)	3	1	4	2

50. Hot cracks occur in the weld and fusion zone as the metal solidifies. Which of the following are the cases for hot cracks?

1. Presence of sulphur and phosphorous in the base metal.
2. High carbon or alloy content of the base metal
3. Moisture in the joint or electrode
4. Joint restraint

Select the correct answer using the code given below:

- | | |
|----------------|-------------------|
| (a) 1, 2 and 4 | (b) 1, 2 and 3 |
| (c) 3 and 4 | (d) 1, 2, 3 and 4 |

51. Which of the following effects are possible due to residual stresses in welding?

1. Reduce dimensional stability
2. Welding cracking
3. Effect on fatigue strength
4. Reduction in the creep strength

Select the correct answer:

- | | |
|------------------|-------------------|
| (a) 1 and 2 only | (b) 2 and 3 only |
| (c) 1 and 3 only | (d) 1, 2, 3 and 4 |

52. The main criterion for selection of electrode diameter in arc welding is

- | | |
|---------------------------|---------------------------|
| (a) material to be welded | (b) thickness of material |
| (c) voltage used | (d) current used |

53. Which of the following is preferred for welding of non-ferrous metals by arc welding?

- | | |
|-----------------------|------------------------|
| (a) A.C low frequency | (b) A.C high frequency |
| (c) D.C | (d) all the above |

54. The material used for coating the electrode is called:

- | | |
|----------------|----------|
| (a) binder | (b) slag |
| (c) deoxidizer | (d) flux |

55. Following gases are used in tungsten inert gas welding

- | | |
|------------------------------------|----------------------|
| (a) CO_2 and H_2 | (b) argon and neon |
| (c) helium and neon | (d) argon and helium |

56. T-joint weld is used

- (a) where longitudinal shear is present
- (b) where severe loading is encountered and the upper surface of both pieces must be in the same plane.
- (c) to join two pieces of metal in the same manner as revet joint metals
- (d) to join two pieces perpendicularly

57. Copper is

- (a) easily spot welded
- (b) very difficult to be spot welded
- (c) as good for spot welding as any other material.
- (d) preferred to be welded by spot welding.

58. Two sheets of same material but different thickness can be butt welded by

- | | |
|-------------------------------|--|
| (a) adjustment of the current | (b) time duration of current |
| (c) pressure applied | (d) changing the size of one electrode |

59. Projection welding is
(a) multi-spot welding process (b) continuous spot welding process
(c) used to form mesh (d) used to make cantilevers
60. Grey cast iron is best welded applied
(a) TIG (b) MIG
(c) submerged work (d) oxy-acetylene welding
61. Seam welding is
(a) multi-spot welding process (b) continuous spot welding process
(c) used to form mesh (d) used for welding cylindrical objects
62. Laser welding finds widest applications in
(a) heavy industry (b) structural work
(c) process industry (d) electronic industry
63. In arc welding, temperature of the following order may be generated
(a) 1000°C (b) 1500°C
(c) 5500°C (d) 8000°C
64. Long arc lengths in welding would require the voltages and currents respectively as follows:
(a) high, high (b) low, low
(c) high, low (d) low, high
65. Fluxes are used in welding in order to protect the molten metal and the surfaces to be joined from
(a) oxidation (b) carburizing
(c) distortion and warping (d) unequal temperature distribution
66. Metal deposited on to the workpiece from the electrode
(a) falls because of gravity
(b) is attracted towards the workpiece due to the positive polarity of the workpiece
(c) is attracted towards the workpiece due to the negative polarity of the workpiece
(d) is attracted due to electromagnetic action.
67. The phenomenon of weld decay occurs in
(a) cast iron (b) brass
(c) bronze (d) stainless steel
68. Weld spatter is
(a) flux (b) electrode coating
(c) welding defect (d) welding technique
69. Arc blow occurs in
(a) gas welding (b) gas cutting
(c) DC arc welding (d) AC arc welding
70. Low hydrogen electrodes are baked prior to use in order that
(a) proper strength is obtained (b) welding is free from blow
(c) welding is free from moisture pick up (d) current required is minimum
71. In straight polarity welding
(a) electrode holder is connected to the negative and work to positive
(b) electrode holder is connected to the positive and work to negative
(c) work is positive and holder is earthed
(d) holder is positive and work is earthed.

72. In thermit welding, the iron oxide and aluminium are mixed in the proportion of
(a) 1 : 1 (b) 3 : 1
(c) 1 : 3 (d) mixture is of different oxides
(e) none of the above
73. TIG welding is best suited for welding
(a) mild steel (b) stainless steel
(c) carbon steel (d) aluminium
74. In the manual TIG welding, the angle of the electrode holder with the direction of welding normally is
(a) 30° (b) 45°
(c) 60° (d) 70°
75. Arc stability is better with
(a) AC welding
(b) DC welding
(c) both AC and DC welding
(d) specially designed wave forms
76. Two stainless steel foils of 0.1 mm thickness are to be joined. Which of the following process would be best suited
(a) gas welding (b) electro slag welding
(c) TIG welding (d) MIG welding
77. Arc length in arc welding should be equal to
(a) half the diameter of electrode rod (b) rod diameter
(c) twice the rod diameter (d) 2.5 times the rod diameter
78. In coated electrode in arc welding
(a) both rod and coating melt simultaneously
(b) coating melts first and then rod melts
(c) which melts first depends on polarity
(d) rod melts first and then coating melts
79. The advantages of electroslag welding are
(a) ability to weld metals of great thickness in a single pass without calling for joint preparation
(b) high welding speed
(c) little distortion and good stress distribution across the weld
(d) protection from contamination
80. In arc welding, if arc is too short, it will result in
(a) formation of large globules in an irregular pattern because of wandering of arc, leading to poor fusion with base metal
(b) electrode sticking to the base metal and base metal not melting and bead resting on top of the work, leading to poor fusion and gas and slag holes
(c) arc extinction
(d) operator hazard
81. In braze welding the filler metal is (an other type of fusion welding)
(a) Distributed by capillary action
(b) Melted and deposited at the point where the weld is to be made. The process is performed at the melting point of filler material

- (c) Both of the above
(d) Not required
82. Too high welding current in arc welding would result in
(a) excessive piling up of weld metal, poor penetration, wasted electrodes
(b) excessive spatter, under cutting along edges, irregular deposits, wasted electrodes.
(c) too small bead, weak weld and wasted electrodes
(d) excessive piling up of weld metal, overlapping without penetration of edges, wasted electrodes
83. The temperature of the inner luminous cone of neutral flame is the order of
(a) 1000°C (b) 2000°C
(c) 2500°C (d) 3500°C
84. The maximum flame temperature occurs at
(a) the tip of flame (b) the inner cone
(c) next to the inner cone (d) at the outer cone
85. Distortion in welding occurs due to
(a) use of excessive current (b) improper clamping methods
(c) use of wrong electrodes (d) oxidation of weld pool
86. Oxygen to acetylene ratio in case of neutral flame by weight is
(a) 0.8 : 1.0 (b) 3 : 1
(c) 1.2 : 1 (d) 2 : 1
87. The main advantage of MIG welding over TIG welding is that
(a) former can be used to weld hard to weld metal
(b) former permits use of large currents thereby allowing higher deposition
(c) welding rate is very fast
(d) welding is completely automatic
88. Which of the following materials is best cut by oxy-cutting process
(a) brass (b) bronze
(c) stainless steel (d) mild steel
89. The acetylene cylinder is filled with a material saturated with
(a) calcium carbide (b) calcium oxide
(c) acetone (d) acetylene
90. The commonly used flux for brazing is
(a) resin (b) NH_4Cl
(c) borax (d) soft iron
91. Two pipes of inner diameter 100 mm and outer diameter 110 mm each are joined by flash-butt welding using 30 V power supply. At the interface, 1 mm of material melts from each pipe which has a resistance of 42.4Ω . If the unit melt energy of 64.4 MJm^{-3} , then time required for welding (in s) is
(a) 1 (b) 5
(c) 10 (d) 20

OOOO

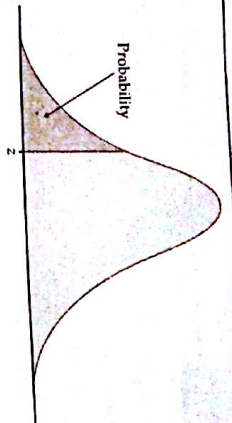
ANSWERS

WELDING

1. (d)	2. (d)	3. (c)	4. (c)	5. (b)	6. (c)	7. (a)
8. (d)	9. (d)	10. (a)	11. (c)	12. (b)	13. (c)	14. (d)
15. (c)	16. (b)	17. (b)	18. (c)	19. (c)	20. (d)	21. (b)
22. (d)	23. (d)	24. (a)	25. (a)	26. (c)	27. (d)	28. (d)
29. (b)	30. (c)	31. (c)	32. (a)	33. (d)	34. (d)	35. (b)
36. (c)	37. (c)	38. (b)	39. (b)	40. (a)	41. (a)	42. (d)
43. (d)	44. (b)	45. (c)	46. (c)	47. (a)	48. (d)	49. (a)
50. (d)	51. (d)	52. (b)	53. (c)	54. (d)	55. (d)	56. (a)
57. (b)	58. (d)	59. (a)	60. (d)	61. (b)	62. (d)	63. (c)
64. (c)	65. (a)	66. (d)	67. (d)	68. (c)	69. (c)	70. (c)
71. (a)	72. (b)	73. (d)	74. (a)	75. (b)	76. (c)	77. (b)
78. (d)	79. (a)	80. (b)	81. (b)	82. (b)	83. (d)	84. (b)
85. (a)	86. (b)	87. (b)	88. (d)	89. (c)	90. (c)	91. (c)

APPENDIX

Table entry for z is
the area under the
standard normal curve
to the left of z.



Standard Normal Probabilities

-3.4	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
-3.3	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
-3.2	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
-3.1	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
-3.0	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013
-2.9	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016
-2.8	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019
-2.7	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
-2.6	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035
-2.5	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047
-2.4	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062	0.0062
-2.3	0.0082	0.0082	0.0082	0.0082	0.0082	0.0082	0.0082	0.0082	0.0082
-2.2	0.0107	0.0107	0.0107	0.0107	0.0107	0.0107	0.0107	0.0107	0.0107
-2.1	0.0139	0.0139	0.0139	0.0139	0.0139	0.0139	0.0139	0.0139	0.0139
-2.0	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179	0.0179
-1.9	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228	0.0228
-1.8	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287
-1.7	0.0359	0.0351	0.0351	0.0351	0.0351	0.0351	0.0351	0.0351	0.0351
-1.6	0.0446	0.0436	0.0436	0.0436	0.0436	0.0436	0.0436	0.0436	0.0436
-1.5	0.0548	0.0537	0.0537	0.0537	0.0537	0.0537	0.0537	0.0537	0.0537
-1.4	0.0668	0.0655	0.0655	0.0655	0.0655	0.0655	0.0655	0.0655	0.0655
-1.3	0.0808	0.0793	0.0793	0.0793	0.0793	0.0793	0.0793	0.0793	0.0793
-1.2	0.0968	0.0951	0.0951	0.0951	0.0951	0.0951	0.0951	0.0951	0.0951
-1.1	0.1151	0.1131	0.1131	0.1131	0.1131	0.1131	0.1131	0.1131	0.1131
-1.0	0.1357	0.1336	0.1336	0.1336	0.1336	0.1336	0.1336	0.1336	0.1336
-0.9	0.1587	0.1562	0.1562	0.1562	0.1562	0.1562	0.1562	0.1562	0.1562
-0.8	0.1841	0.1814	0.1814	0.1814	0.1814	0.1814	0.1814	0.1814	0.1814
-0.7	0.2119	0.2090	0.2090	0.2090	0.2090	0.2090	0.2090	0.2090	0.2090
-0.6	0.2420	0.2389	0.2389	0.2389	0.2389	0.2389	0.2389	0.2389	0.2389
-0.5	0.3085	0.3050	0.3050	0.3050	0.3050	0.3050	0.3050	0.3050	0.3050
-0.4	0.3446	0.3409	0.3409	0.3409	0.3409	0.3409	0.3409	0.3409	0.3409
-0.3	0.3821	0.3783	0.3783	0.3783	0.3783	0.3783	0.3783	0.3783	0.3783
-0.2	0.4207	0.4168	0.4168	0.4168	0.4168	0.4168	0.4168	0.4168	0.4168
-0.1	0.4602	0.4562	0.4562	0.4562	0.4562	0.4562	0.4562	0.4562	0.4562
0.0	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
0.1	0.5398	0.5438	0.5438	0.5438	0.5438	0.5438	0.5438	0.5438	0.5438
0.2	0.5793	0.5832	0.5832	0.5832	0.5832	0.5832	0.5832	0.5832	0.5832
0.3	0.6179	0.6215	0.6215	0.6215	0.6215	0.6215	0.6215	0.6215	0.6215
0.4	0.6554	0.6591	0.6591	0.6591	0.6591	0.6591	0.6591	0.6591	0.6591
0.5	0.6915	0.6950	0.6950	0.6950	0.6950	0.6950	0.6950	0.6950	0.6950
0.6	0.7257	0.7291	0.7291	0.7291	0.7291	0.7291	0.7291	0.7291	0.7291
0.7	0.7580	0.7614	0.7614	0.7614	0.7614	0.7614	0.7614	0.7614	0.7614
0.8	0.7868	0.7901	0.7901	0.7901	0.7901	0.7901	0.7901	0.7901	0.7901
0.9	0.8143	0.8176	0.8176	0.8176	0.8176	0.8176	0.8176	0.8176	0.8176
1.0	0.8413	0.8446	0.8446	0.8446	0.8446	0.8446	0.8446	0.8446	0.8446
1.1	0.8643	0.8676	0.8676	0.8676	0.8676	0.8676	0.8676	0.8676	0.8676
1.2	0.8849	0.8882	0.8882	0.8882	0.8882	0.8882	0.8882	0.8882	0.8882
1.3	0.9032	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064	0.9064
1.4	0.9192	0.9222	0.9222	0.9222	0.9222	0.9222	0.9222	0.9222	0.9222
1.5	0.9312	0.9345	0.9345	0.9345	0.9345	0.9345	0.9345	0.9345	0.9345
1.6	0.9452	0.9484	0.9484	0.9484	0.9484	0.9484	0.9484	0.9484	0.9484
1.7	0.9554	0.9584	0.9584	0.9584	0.9584	0.9584	0.9584	0.9584	0.9584
1.8	0.9641	0.9669	0.9669	0.9669	0.9669	0.9669	0.9669	0.9669	0.9669
1.9	0.9713	0.9738	0.9738	0.9738	0.9738	0.9738	0.9738	0.9738	0.9738
2.0	0.9772	0.9798	0.9798	0.9798	0.9798	0.9798	0.9798	0.9798	0.9798
2.1	0.9821	0.9846	0.9846	0.9846	0.9846	0.9846	0.9846	0.9846	0.9846
2.2	0.9851	0.9876	0.9876	0.9876	0.9876	0.9876	0.9876	0.9876	0.9876
2.3	0.9893	0.9906	0.9906	0.9906	0.9906	0.9906	0.9906	0.9906	0.9906
2.4	0.9918	0.9922	0.9922	0.9922	0.9922	0.9922	0.9922	0.9922	0.9922
2.5	0.9938	0.9941	0.9941	0.9941	0.9941	0.9941	0.9941	0.9941	0.9941
2.6	0.9953	0.9955	0.9955	0.9955	0.9955	0.9955	0.9955	0.9955	0.9955
2.7	0.9965	0.9966	0.9966	0.9966	0.9966	0.9966	0.9966	0.9966	0.9966
2.8	0.9974	0.9975	0.9975	0.9975	0.9975	0.9975	0.9975	0.9975	0.9975
2.9	0.9981	0.9982	0.9982	0.9982	0.9982	0.9982	0.9982	0.9982	0.9982
3.0	0.9987	0.9987	0.9987	0.9987	0.9987	0.9987	0.9987	0.9987	0.9987
3.1	0.9990	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991
3.2	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994
3.3	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997

Index

3-2-1 Principle 257

A

Abrasive Jet Machining 238
Acceptance Test for Lathe 43
Acceptance Test of Milling 45
Acceptance Tests 43
Acceptance Tests for Radial Drilling Machine 46
Accuracy 5
Acidic Coating 424
Adhesive Bonding 419
Aging 363
Allotropy of Iron 65
Allowance 10
Aluminum Alloy 105
Angle Blocks 23
Anisotropy 363
Annealing 87
Arc Blow 398
Assumptions of Merchants Circle 191
Austempering 84
Autocollimator 31

B

Babbitt Metal 113
Back Rake Angle 180
Back Up Rolls 346
Barreling 327
Basic Coatings 424
Bead Geometry 383
Bell Metal 114

Bend Radius 363
Bend Test 363
Bendability 363
Bending 360
Biaxial Stretchability 363
Binary Phase Diagram 60
Blank 363
Blank Holder 363
Blanking 352, 363
Blow Moulding 158
Boring 239
Brazing 418
Broaching 240
Bulge Test 363

C

Camber Rolls 346
Carburizing 91
Case Hardening 91
Cast Hard Alloys 225
Cast Iron 69
Casting Defects 160
Cellulose 423
Cemented Carbides 225
Centrifuging 157
Ceramic 225
Ceramics 55
Chips 186
 Continuous Chips 186
 Discontinuous Chips 186
 Build Up Edge 186
Clearance Fit 9

Coated Tools 226
Coining 361, 364
Cold Chamber Die Casting 155
Cold Shut 154
Cold Working 305
Collapsibility 153
Comparator 31
Composite Materials 59
Constant Current Type Transformer 385
Constant Voltage Transformer 385
Core Drilling 240
Cosine Error 27
Counter Boring 240
Counter Sinking 240
Creep 103
Crystal Directions 100
Crystal Planes 102
Crystal Systems 97
Cubic Boron Nitride 226
Cup Test 364
Cupola 161
Cupping 364
Cutting Fluids 206
Cutting Force 189
Cyaniding 93

D

Dendritic Growth 153
Dead Mild 75
Deep Cyaniding 93
Deep Drawing 353, 364
Defects in Deep Drawing 359
Defects in Welding 428
 Flange Wrinkle 360
 Wall Wrinkle 360
 Step Rings 360
 Draw Marks 360
 Orange Peel 360
 Scratches 360
 Fractured Flange and Bottom 360
 Corner Fracture 360
 Miss-strike 360
 Directional Earing 360
Design of Limit Gauges 18
Determination of Shear Angle 192
Diamond 226
Die Casting 155
Diffusion Annealing 88

Draft Allowance 141
Draw Bead 364
Drawability 364
Drill Geometry 241
Drilling 239
Dry Strength 152
Ductile Iron 73
Duralium 113
Duty Cycle 399

E

E System 38
Economics of Machining 218
Edge Dislocation 78
Edging 324
Electro Chemical Machining 231
Electro Gas 400
Electro Slag 400
Electrode Discharge Machining 235
Electron Beam Welding 415
End Cutting Edge Angle 183
Erichsen Test 364
Ernest and Merchant Theory 193
Erratic Error 26
Errors 26
Eutectic Reaction 66
Eutectoid Reaction 66
Explosive Welding 414
Extrusion 311
 Forward 311
 Backward 312
 Hydrostatic 313
 Impact 314
Extrusion Defect 324

F

Fillet Weld 426
Fixtures 256
Flame Hardening 95
Flash Butt Welding 412
Flatness 31
Flaw 37
Flowability 153
Fluxes 423
Forging 324
 Open Die 324
 Closed Die 325

Impression Die 325
 Forming Limit Diagram 364
 Free Cutting Steel 75
 Frenkel Defect 77
 Friction Welding 412
 Fukui Cup Test 364
 Full Annealing 87
 Fullering 324
 Furnaces 160
 Open-hearth (Acid and Basic) 160
 Electric-arc (Acid and Basic) 160
 Converter (Acid Side-blow) 160
 Electric Induction (Acid and Basic) 160

G

Gas Carburising 92
 Gas Cutting 421
 Gas Cyaniding 94
 Gas Welding 419
 Gating System 147
 Gauge Material 20
 Gear Hobbing 262
 Gear Manufacturing 260
 Gear Shaping 262
 General Purpose (ISO) Gauge 20
 German Silver 114
 Gibbs Phase Rule 60
 Grade 230
 Grain Boundary Defect 77
 Gray Cast Iron 72
 Green Strength 152
 Grinding 226
 Surface Grinding 227
 Cylindrical Grinding 227
 Center-less Grinding 227
 Form Grinding 227
 Abrasive Cut Off 227
 Abrasive Belt Grinding 227
 Manual Grinding 227
 Creep Feed Grinding 227
 Centre Less Grinding 228
 Grinding Processes 227
 Gun Metal 114

H

Hardening 88
 Hardness Test 104

Heat Resisting Steels 75
 High Carbon 75
 High Carbon Steel 224
 High Frequency Resistance Welding 411
 High Speed Steel 76, 224
 Hole Basis System 9
 Hot Chamber Die Casting 155
 Hot Working 305
 Hubbing 326

I

Inconel 114
 Induction Hardening 94
 Inspection Gauges 20
 Interchangeability 6
 Interference Fit 10
 Interferometry 27
 Interstitial Defect 77
 Investment Casting 159
 Iron-carbon Phase Diagram 65
 Ironing 364
 ISO Designation of Grinding Wheel 230

J

Jigs 256

K

Killed Steels 74

L

Lancing 362
 Laser Beam Welding 416
 Lay 37
 Lee and Shaffer 194
 Line Defects 78
 Loam Sand 153

M

M System 38
 Machinability 217
 Machinability Index 217
 Machining Allowance 141
 Magnet Steel 75
 Malleable Cast Iron 73
 Marging Steels 76

Martempering 85
 Mathematical Errors 27
 Mechanical Comparators 31
 Mechanite Cast Iron 73
 Medium Carbon 75
 Metals 53
 Micrometer 26
 Mikrokator 32
 Mild Steel 75
 Milling 244
 Peripheral or Slab 244
 Face 244
 End 245
 Gang 245
 Straddle 245
 Up 246
 Down 246
 Mechanics of 246
 Misrun 154
 Monel Metal 114
 Multipoint Cutting Tool 179
 Muntz Metal 114

N

Nibbling 362
 Nitriding 93
 Non-metals 53
 Nose Radius 183
 Notching 362

O

Optical Flat 29
 Organic Polymer 53
 Orthogonal Cutting 184

P

Pack Carburizing 91
 Pack Drilling 240
 Parting 362
 Patterns 141
 Perforating 362
 Peritectic Reaction 66
 Permeability 152
 Permeability Number 152
 Phase Diagrams 59
 Plasma Arc Welding 399
 Pneumatic Comparators 33

Points Defects 76
 Powder Metallurgy 254
 Precision 5
 Precision Ball Measurement 24
 Pressure Die Casting 155
 Process Annealing 88
 Projection Welding 403
 Punching 352

Q

Quenching Medium 90

R

Reaming 240
 Redrawing 355
 Refractoriness 153
 Resistance Welding 401
 Rimed Steels 74
 Risers 142
 Roll Forging 326
 Rolling 342
 4 High 346
 Sandzmier 347
 3 High 347
 Planetary 348
 Tandom 348
 Rolling Defects 348
 Wavy Edges 348
 Spread 348
 Crocodile Crack 349
 Rutile 423

S

Schottky Defect 77
 Screw Dislocation 79
 Screw Thread Manufacturing 259
 Thread Chasing 259
 Die Threading 259
 Tapping 259
 Thread Milling 259
 Thread Rolling 259
 Thread Grinding 260
 Screw Thread Metrology 41
 Seam Welding 403
 Selective Assembly 6, 7
 Semicentrifugal Casting 156
 Semi-killed Steels 74

Shaft Basis System 9
 Shell Moulding 158
 Shielded Metal Arc Welding 384
 Shock Resisting Steels 76
 Short Period Error 26
 Shrinkage Allowance 141
 Sialon (Si-al-o-n) 225
 Side Cutting 181
 Side Cutting Edge Angle 181
 Side Rake Angle 182
 Side Relief Angle 182
 Sigma Comparators 32
 Sine Bar 23
 Sine Error 27
 Single Point Cutting Tool 179
 Skin Forming 153
 Slip Gauges 22
 Slitting 362
 Slush Casting 157
 Sodium Silicate (Co₂) Moulding 158
 Soldering 418
 Solid State Welding Processes 412
 Spheroidise Annealing 88
 Spirit Level 31
 Spot Welding 402
 Stacking Faults 78
 Stainless Steels 76
 Straight Edge 30
 Straightness 30
 Structure 229
 Submerged Arc Welding 396
 Substitutional Defect 77
 Surface Defects 77
 Surface Finish 37
 Surfacing 419
 Swaging 326
 System Error (Systematic Error) 26

T

Talysurf 40
 Taylors Tool Life Equation 211
 Tempering 90
 Tensile Test 104
 Thermal Stability 153
 Thermit Welding Process 417
 Thrust Force 189
 Tilt Boundary Defect 77
 Time Temperature Transformation (TTT) Diagram 83

Tolerance Stik 17
 Tolerances 8
 Tool Materials 224
 Tool Signature 183
 ASA 183
 British 184
 Normal or Orthogonal Rake 184
 Tool Wear 208
 Diffusion 208
 Adhesion 208
 Abrasion 209
 Fatigue 209
 Oxidation 209
 Flank 210
 Crater 210
 Transition Fit 10
 Trepanning 240
 True Centrifugal 156
 Tube Drawing 310
 Tungsten Inert Gas Welding (TIG) 397
 Twin Boundary Defect 78

U

UCON 225
 Ultrasonic Machining 237
 Ultrasonic Welding 413
 Unary Phase Diagram 60
 Upset Forging 326

V

Vacancy Defect 76
 Vernier Calipers 26

W

Warm Working 305
 Wheel Dressing 231
 White Cast Iron 73
 Wire Drawing 309
 Work Shop Gauges 19
 Wrought Iron 73

Y

Y-alloy 113
 Yield Point Phenomenon 79

Revised & Improved Edition

A text book on

Production Engineering

Useful for IAS, IES, GATE, PSUs and other competitive examinations

About the Author



Dr. Steadash Kumar Singh holds Masters and PhD degree from IIT Delhi. During his teachership, he received a gold medal from AIU. He has vast experience of effective teaching in IES, IAS, GATE and other competitive examinations. He excels in teaching methods particularly in the fields of Production Engineering and Material Science. He has authored several international journal papers and received the sponsored project grants from All India Council of Technical Education (AICTE) and Department of Science and Technology (DST), Govt. of India. His area of research is in finite element in sheet metal forming, hydroforming, warm forming and characterization of materials in the warm and hot conditions. His contributions are frequently researchers in highly reputed international journals. He is awarded Young Scientist award from DST and career award for young teachers from AICTE. Prior to being a Professor at GRIET, he has worked for BHEL. He has also served government of India as an IES officer.

About MADE EASY

MADE EASY Group is one of the India's best institution for engineers. It was established with the aim to help and guide ambitious engineering graduates to achieve their career objectives. MADE EASY has placed thousands of engineering graduates in top positions of various services & posts including Civil Services, Engineering Services & Public Sector Units. MADE EASY team is headed by its Director Mr. B. Singh (Ex. IES) & comprises of highly experienced & most reputed experienced teachers/institutions, IES qualified TOP rankers & professional experts of various fields who are masters of their subjects and well known all over India for their contribution in books and international journals.

MADE EASY Education provides high quality & targeted, comprehensive classroom and postal training programmes for IAS, IES, GATE, PSUs and other competitive examinations for following streams:

- | | | |
|----------------------------|---------------------------|---------------------------|
| 1. Civil Engineering | 2. Mechanical Engineering | 3. Electrical Engineering |
| 4. Electronics Engineering | 5. Computer Science/IT | 6. Instrumentation Engg. |

MADE EASY Centres:

Delhi | Hyderabad | Noida | Bhopal | Jaipur | Lucknow | Indore | Bhubaneswar

MADE EASY Publications

A unit of MADE EASY Group

Corporate Office: 44/1, Kalu Sarai (Near Hauz Khas Metro Station), New Delhi - 110016

Phone: 011-45124613, 23560692, 0-9958905030 | Website: www.madeeasypublications.org



Rs. 375.00